RECENT CHANGES IN LAND USE IN SOUTH-EAST SCOTLAND

An Approach with Integration of Remote Sensing and GIS

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Ph.D

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1992

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ABSTRACT

The overall aim of this thesis is to investigate and to evaluate an alternative method for monitoring changes in land use, through a selected study for a test location in South-East Scotland, with application of state-of-the-art approaches where possible.

The specific objectives are: (1) to consider existing methods for image classification and integrated mapping of land use/land cover; (2) to construct the patterns and trends of recent changes in land use/land cover in South-East Scotland with a combination of different data sources and methods; (3) to test the feasibility of remote sensing data in land use/land cover studies integrated with GIS techniques and (4) to evaluate different data and methods adopted in the study and to explore their relationships.

Using the available data sources of agricultural statistics, Landsat images and additional statistical and cartographic data, the principal methods include cartographic representation of the parish summaries, analysis of their temporal changes and establishment of relationships between different land use variables, as well as training, classification, accuracy assessment and comparison of Landsat images. They are integrated in the GIS to meet the research requirements and to supplement findings of each other.

The main facets of changes in land use in South-East Scotland since the late 1940s are revealed in the study, through analysis of the available parish summaries. The general characteristics of the land use/land cover patterns show a continuation of previous findings. They also reflect changes in government policies.

With imagery analysis as the principal thrust of the study, two Landsat images have been used for mapping land cover in the study area in 1984 and 1986. They also serve the purpose of testing the feasibility of Landsat data for detection of changes in land use/land cover. An overall accuracy of 82% has been achieved for classification of the MSS image (24 April 1984) and 88% for analysis of the TM image (14 September 1986). The interface between remote sensing and GIS has shown benefits in imagery analysis and allows comparisons of the classification results to be carried out and justified.

Characterised by its integration of data and methods, this study exemplifies a way of demonstrating both the spatial distribution and the aspatial information of regional land use. Landsat imagery affords an effective means of establishing patterns of land use as well as monitoring and measuring its dynamics, but an incorporation of other data sources is important for the success of imagery analysis and for the production of a complete picture of regional land use/land cover, especially in long term retrospective studies. The importance of error analysis in any remote sensing work is also stressed.

Declaration

This thesis has been composed by myself and the work is my own.

HUI XU

September 1992

ACKNOWLEDGEMENTS

I am grateful to my supervisors, Dr. G. M. Robinson and Dr. J. A. T. Young, for their unfailing help, guidance and encouragement. I also wish to thank Mr. J. M. Hotson and Mrs. A. Bayley of Edinburgh University Data Library for offering assistance in mapping the Agricultural Census: parish summaries. Dr. Graham Russell at the Edinburgh School of Agriculture is acknowledged here for providing data on Arable Crop Experiments and Farm Cropping Programme of Bush Estate, which formed the important ground data in the imagery analysis.

Many people in the Department of Geography of Edinburgh University have been helpful towards the completion of my Ph.D study. Among them, Chris Place, Steve Dowers, David Gray and Bob Hodgart deserve special mention. I benefitted extensively from the Departmental seminars too.

I also would like to acknowledge Mr. J. O. Bailey at the University of Bristol for comments on several Chapters of this thesis.

I owe gratitude to the assistance and encouragement from my parents and many of my friends, in particular the help from Dr. Y.P. Wang. The Chinese government and the British Council are also sincerely acknowledged for offering the sponsorship.

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CHAPTER I

INTRODUCTION: The Monitoring of Changes in Land Use

The overall aim of this research project is to investigate and to evaluate an alternative method for monitoring changes in land use/land cover, through a selected study for a test location in South-East Scotland, with application of state-of-the-art approaches where possible.

1.1 Review of Approaches

Land use study has long been a research focus of Man and Earth relationships with its practical and political importance (Rhind and Hudson, 1980:PP3-4). The use of land has an impact on both people and the surrounding environment. Also, it interacts with future patterns of land use. The fact that there is only a finite amount of land has brought considerable power to those who possess land and have the right to influence or control land use. Therefore, "control of land and land use has been and remains a politically contentious issue" (Rhind and Hudson, 1980:P3). Apart from the political heat generated by the issue of land, the central position of land in economic and social life has led to considerable State intervention in land use control and the land market (Rhind and Hudson, 1980:P4). Government controls and other influences on land use have grown and expanded substantially in recent decades, especially since the Second World War (Mather, 1986:P96). "Indeed, since 1947, planning control over the use of land and government policy, either directly or indirectly, have been major determinants of land use in both rural and urban areas" (Best and Coppock, 1962:P26).

Detection of changes in land use and updating information on the distribution and dynamics of land use are also important in making planning decisions, optimising land management policies and creating laws and policies to overcome various problems concerning environmental processes and improving or maintaining living conditions or standards. Information on regional land use and changes through time is often required for the studies of other key issues, such as land use and decision making, land use and environment, land use and government (Mather, 1986:PP26-97). One very timely example is the obvious importance of monitoring land use at present when surpluses dictate the need for an effective change in agricultural strategy throughout Europe.

Furthermore, land use information is of significance in scholarly and scientific research since natural and regional land use patterns reflect the interaction between environment and human activities: "The past, present and future arrangements and juxtapositions of land use have occupied academics for many years" (Rhind and Hudson, 1980:P5). For instance, comparing different areas and modelling land use pattern are quite common tasks carried out by geographers, economists and planners. Indeed, "spatial variation in land use acts either as a back-cloth to work in other disciplines or, alternatively, is an integral part of multi-disciplinary research" (Rhind and Hudson, 1980:P5).

The dynamic nature of land use must be understood in any land use study. It is a fact that land use at a particular location rarely remains constant. The changing nature of land use results from the changing nature of the many factors which affect it, *e.g.*, improvements in technology and changing government policy. "The nature of land use in an area is a function of the factors of land production within the prevailing social and political constraints. Land use is influenced by the physical nature of land and its location, by available capital and its distribution, and by the availability and cost of labour. It is also influenced by the social and political climate in which they operate" (Mather, 1986:PP23-24). As restructuring has occurred in the industrial world during the past decades, contemporary rural land use has developed a new style and content characterised by complexity. Land use remains a central political and practical issue in a contemporary society. While methods of land use data capture are becoming increasingly sophisticated and technical, the study of land use has been changing its characteristics, in terms of making use of new data sources, implementing improved technology in data capture, storage, manipulation and output, or even offering updated explanatory models.

As Anderson *et al* (1976) pointed out, "one of the prime pre-requisites for better use of land is information on existing land use patterns and changes through time." Thus, describing the spatial distribution patterns of land use and thereafter monitoring its changes form a critical part of land use study. The initial requirement is for a land use survey which will serve as a datum for subsequent studies.

The usual objectives of conventional land use surveys are generally two-fold, as postulated by Jeffers (1970). Firstly, they are to produce estimates of the proportions of land used for various defined purposes and hence of the actual area of land devoted to these purposes, and secondly, to produce maps of the area surveyed showing the spatial distribution of various land use classes. Different kinds of work such as data collection, manipulation and cartographic representation are often required to achieve these objectives.

Traditional land use surveys are often based on detailed local field work and mapping. They are labour-intensive and hence costly, time-consuming and difficult to organise. The data so collected also lack uniformity or comparability of classifications over time or between areas. For example, the third survey of Great Britain has been undertaken by the Institute of Terrestrial Ecology (ITE). It depends extensively on field observation of a small sample of 1 km squares and has been designed to give acceptable information for Great Britain as a whole. Although ITE has extensive experience of collecting field data and expertise in statistics and in the use of micro-computers, its staff in these fields is small. The two sample field surveys undertaken by ITE in 1978 and 1984 provide a basis for examining changes between dates. But the samples (c. 80 sites in 1978 and c. 120 in 1984) are too small to give estimates for the subdivisions of Scotland and for some of the minor categories (Coppock and Kirby, 1987).

Modern technological advances have been applied to facilitate the monitoring of changes in land use. The availability of aerial photographs and satellite imagery has made the task of land use survey swifter. Significant progress in land use survey has been achieved over the past decades. Aerial photographs provide one of the most detailed and comprehensive records of changing vegetation cover in Britain. They extend back to the

1920s and cover the period from about 1945 to the present (Fuller, 1983). Interpretation of aerial photographs has been well developed and is becoming a routine technique in land use/land cover analysis and mapping. One example is the National Countryside Monitoring Scheme (NCMS) conducted by the Nature Conservancy Council (NCC) on behalf of the Countryside Commission for Scotland (CCS) for a study of changes in wildlife habitats throughout Great Britain, based entirely on the interpretation and comparison of samples of aerial photographs. NCC was interpreting photography for 1970-75 to provide a basis for estimating changes between the late 1940s/early 1950s and 1970-75. Also these interpretations can be used as a base-line for comparison with later photographic interpretation to establish recent changes (Coppock and Kirby, 1987). The recent Scottish national survey is worth mentioning here. This is undertaken by the Macaulay Land Use Research Institute (MLURI) using aerial photographs at 1:24 000 scale to monitor changes in landscape features. Initiated in 1989, "The Land Cover of Scotland by air photo interpretation" is a project to determine the land cover of Scotland, classified into a variety of type, through the interpretation of air photos and for the presentation of the results as a computer-stored digitised data-set (MLURI, 1989). The aerial photographs have been supplied by the Scottish Development Department (SDD) and interpreted by scientific staff of the Land Use Division of MLURI. The results are compiled on to 1:25000 scale 24 000 Ordnance Survey (OS) maps. The map compilations are then digitised and converted to vector, quadtree and raster data formats. These computer-stored data-sets can be readily used for output or for further analysis.

Meanwhile, the use of satellite digital data makes the compilation of land use maps for a large area a much more realistic proposition than when field survey was the only available technique. Satellite imagery affords an effective means of detecting changes in land use/land cover and updating information on the distribution and dynamics of land use/land cover. The past twenty years since the launch of the first Landsat satellite have seen much progress and maturing in the application of remotely sensed Landsat data. Remote sensing has become an operational technique with its increasing acceptance as a useful source of data for studies of the Earth's surface.

Other than surveys, censuses conducted by agricultural ministries and other government departments have been the main source of information on land use, especially in the absence of regular comprehensive land use surveys (Mather, 1986:PP100-103). Important developments in Geographical Information Systems (GIS) have led to a variety of facilities for carrying out functions for data handling by means of computers. Combinations of different data sources are also possible via GIS to construct a full picture of regional land use/land cover. The wide applications of remote sensing and GIS in geographical research have offered improved means of describing changes in land use/land cover and increased the efficiency of data manipulation and representation. Examples of this include map digitising, storage, retrieval and output, as well as computer mapping of statistical data.

Moreover, the integration of remote sensing and the computer-based systems has brought a new prospect to land use/land cover studies. Rapid advances in computer technology in terms of interactive capability and lowered computational costs have increased users' ability to interact with GIS processes whilst remote sensing generates a wide variety of data as input to GIS. The integration of the two technologies helps to meet the need for database management and data administration. In fact, one of the current research foci has been the synergism of remote sensing analysis and GIS. The input of certain ancillary data from GIS is often required by remote sensing analysis while the transformation of remote sensing outputs can be used as a new thematic overlay for automated plotting or for further analysis in GIS with updated data planes. Much published work shows the integration of remote sensing and GIS (*e.g.* Goodenough *et al* 1984; Graetz *et al*, 1988; Quarmby and Cushnie, 1989; Wright and Morrice, 1988). The work by Goodenough *et al* (1984) demonstrated the capability of drawing data from Canadian GIS and sending image-classified data to statistics in Canada's GIS. In general, the outcome of integrating information extracted from remote sensing data with other data types by using GIS methods enhances greatly the information content of remote sensing data and provides a highly flexible, efficient means of establishing a datum for subsequent monitoring of land use/land cover.

The current growing emphasis on global environmental research also requires information about land cover phenomena at periodic intervals. The knowledge of land cover and its changes with time is fundamental to achieving the objective of advancing the ability for documenting and predicting changes in the global system. First, studies aimed at improved understanding of the interactive processes require information on land use/land cover distribution so that knowledge obtained at specific sites may be properly applied to its spatial and temporal domains. Second, land cover change over time captures many of the effects of natural processes and human activities which together constitute global change. Remote sensing is seen as an essential tool for studies of global environmental change. It also presents a considerable challenge from the methodological viewpoint to use remote sensing data for mapping land cover in a consistent manner at a large scale (Cihlar *et al*, 1990).

1.2 Context/Rationale for Study in South-East Scotland

Major changes in land use will take place in Europe in the next few years as the effects of changes in agricultural support policies are felt. With Scotland being part of the European Community, studies of changes in land use should keep pace with the dynamics of land use. As reviewed by Coppock and Kirby (1987), field survey, aerial photography and satellite imagery offer the best prospect for monitoring changes in the Scottish landscape. But using satellite imagery successfully as a regular input for land use/land cover monitoring in Scotland requires usable imagery on a routine basis and substantial contextual knowledge of the ground situation to counter the absence of such imagery and the subtlety of the changes in land cover. The lack of consistency in satellite data acquisition also requires a combination of different data sources and methods to monitor changes in land use/land cover.

Previous studies have shown that many changes in rural land use have taken place (*e.g.*, Dawson, 1980; Eadie, 1984; Mather, 1979; Robinson, 1988). Agricultural improvements and the pressure from urban expansion have led to the advance of the upper limit of cultivation, and the recent widespread afforestation has increased the grazing pressure on hill farms.

With respect to the land uses in South-East Scotland, three kinds of changes have been prominent for the past two decades (*e.g.*, Tranter, 1978; Lea *et al*, 1977). They are:

(1). Changes in the rural-urban fringe where urban development at the expense of agricultural land use has been a problem for a long time;

(2). Changes within agricultural land uses such as substitutions of one crop for another in the intensive lowland farming area;

(3). Changes on the boundary areas of the intensive farming and upland farms where land use competition exists between agricultural improvement, recent afforestation and rough pastures.

Therefore, this study has been undertaken because of the long term significance of land use studies and the pressing need for monitoring changes in land use, especially utilising developments in modern technology. The growing recognition and emphasis on global environment research and the challenge of using remote sensing in a consistent manner increase the urgency for an established approach to monitoring changes in land use/land cover.

The available data sources for this study include agricultural statistics, Landsat images, aerial photographs and additional statistical and cartographic data. The use of these data can be combined in an integrated system using GIS to meet the requirements of the research environment. It is not the purpose of this thesis to decide which is the best data or technique. Instead the desire is to learn the strengths and weakness of a variety of data and techniques so as to be in a position to match them against the requirements of different objectives. Agricultural statistics prove to be useful in revealing general changes in the amount of agricultural land allocated to different uses and the relative rates of change in different areas. They are especially useful for a long term retrospective study of land use, or in the absence of other data sources. Satellite remote sensing provides a new means of land use survey and represents an approach concerning alterations to the spatial arrangement of rural land use/land cover. The wide coverage, relative low cost and frequent availability make digital remote sensing data advantageous for developing operational techniques on monitoring changes in land use/land cover. Therefore, the classification and mapping of land use/land cover via the use of Landsat imagery form the focus of this study. The approach is mainly concerned with establishing patterns of land use/land cover and detecting their dynamics. Whilst brief comments and elucidations are given on the distribution and changes in regional land use/land cover, a complete explanation of the pattern which may emerge and an assessment of the degree to which environmental and other factors influence the patterns is a separate issue and is not pursued here.

The main scientific objectives of this study are as follows:

(1). Consideration of existing classification methods and the integrated mapping of land use/land cover;

(2). Description of the structure and trend of recent changes in land use in South-East Scotland with a combination of different data sources and methods;

(3). Test of the method as well as the feasibility of satellite remote sensing data in land use/land cover studies integrated with GIS techniques;

(4). Evaluation of different data sources and methodology adopted in the research and exploration of relationships between them.

1.3 Land Use and Land Cover Monitoring: A case study

The use of digital remotely sensed imagery in natural resource and environmental applications has been, and continues to be, extensively evaluated and used both operationally and experimentally. Although a number of studies have examined applications of Landsat Thematic Mapper (TM) or Multi-Spectral Scanner (MSS) data in land use/land cover mapping, few have been integrated land use studies.

This study is characterised by its integration. The major objectives outlined at the end of the last section are primarily achieved through a case study carried out in the Lammermuir Hills. There is a need for an integrated classification of land cover with a combination of different data sources for a complete picture of regional land use. The study also examines different roles of remote sensing and the analysis of agricultural statistics. The realisation of the interface between an image processing system and GIS permits further exploitation of the potential of each technique. Therefore a system is constructed for monitoring changes in land use/land cover, using the latest technical advances.

Seven chapters are included in this thesis. The main theme and contents of each chapter are briefly mentioned in the following paragraphs.

Chapter 1 is an introduction to the study as a whole, including its overall aim and specific objectives. It also discusses the reasons for the choice of the study and its social, economic and technical significance. Methods and major issues in land use studies are also addressed here.

The following Chapter reviews the relevant literature. The background to the subject of land use and remote sensing is covered through an evaluation of the contributions of others, identifying developments and current trends in research activities, and defining areas of theoretical and empirical weakness.

Chapter 3 gives a description of the research methodology, aiming to establish the nature of the problem and procedures to achieve the goals. It focuses upon and justifies the procedure and approach of the research. The selection of the Lammermuir Hills in South-east Scotland as a study area and its geographical character are also included here. In addition, justification for the relevance and validation of the data used, their appropriateness and reliability is considered in this chapter.

Results of the study are presented in two chapters, Chapter 4 and Chapter 5, concerning the use of major data sources of agricultural statistics and Landsat images respectively. They reveal different aspects of regional land use and the findings of each approach complement the other. Chapter 4 summarises the results from an analysis of the parish summaries for East Lothian and the Lammermuirs between 1947 and 1987 with a brief commentary while Chapter 5 shows the approach to monitoring changes in land use/land cover through integration of remote sensing and GIS.

In Chapter 6, a critical and scientific appraisal is made of the proposed system for monitoring changes in land use/land cover. It provides a brief summary of the major findings, together with a critical review of the methods adopted and an indication of how future studies might be developed. The inter-relationships between different data sources and methods are explored. Comparisons are made with previous studies to reveal the characteristics of this study and underline its contribution. Meanwhile, the limitations of the proposed system are examined and prospects for an improved system are suggested.

In the 'Conclusions', the main contributions of the study are spelt out, together with suggestions for appropriate future developments. This study attempts to construct an approach to monitoring changes in land use, using the latest technical advances where possible. In addition to revealing the characteristics of regional land use, the contribution of the study to the research field extends to further exploiting the potential of remote sensing as an operational tool for land use/land cover monitoring. This is important in conjunction with analysis of other collateral data sources, incorporated through GIS.

CHAPTER II

LAND USE STUDY:

A Long-Standing Issue and its Changing Nature

To understand why and how the project has been undertaken, the scientific background of land use studies need to be explained briefly.

2.1 Land Use Study with Conventional Data Sources

Data from lists and texts provide the earliest land use records which exist in Britain and, indeed, in most other countries too (Rhind and Hudson, 1980:P53). For example, the "Domesday Book" is probably the most remarkable statistical document in the history of Europe. Despite various drawbacks, considerable reconstruction of land use with such statistical data is still possible.

Some important sources of land use information are widely used in tabular form. Some data lists have been used in Britain to provide answers to topical and pressing land use problems. For instance, the British annual agricultural censuses have been collected mainly for the purpose of obtaining estimates of agricultural production (Best and Coppock, 1962) but also include statistics on losses of land from agricultural use to suggest the rate of absorption of agricultural land for urban and other land uses.

Other information such as data on population change compiled from decennial censuses have been used as surrogate, or alternative ways of measuring land use change. For example, estimates of the percentage of urban land in Britain were made by Champion

(1975), based upon his assumption on the relationship between population density and land use.

All too frequently, such lists as the valuation registers are still in manuscript form but the progressive change towards holding the data in computers and proposed changes to the methods of rating ensure that these lists could be an important secondary source of land use information in Britain in the future (Rhind and Hudson, 1980:P55).

Some statistics have provided valuable data sources for land use studies with their wide coverage and continuity over long periods (*e.g.* the British agricultural statistics as mentioned below). However, there are also difficulties in using the data due to the fact that "there are comparatively few purposes for which the available data are ideal and the imprecisions resulting from their mis-use are extremely difficult to quantify" (Rhind and Hudson, 1980:P57).

Among various land use data from lists and texts, the British national agricultural statistics have been widely used. They have been collected on an annual basis since 1866 and have been used in a number of studies for reconstruction of agricultural land use patterns and indication of rates of change in land use (*e.g.* Best and Coppock, 1962; Coppock, 1976; Dawson, 1980; Robinson, 1981 & 1988; Wathern *et al*, 1988). These statistics are usually presented as parish summaries aggregated from individual farm returns. Included within the summaries are such items as number of livestock, size of farm, labour force, acreage farmed, and types and acreage of crops grown within each parish.

Based upon the conveniently mappable data from district summaries of the annual agricultural returns and its cartographic representation, Coppock's agricultural atlases (1964, 1976) provide a general guide to agricultural distribution in Great Britain and present some features of agriculture in maps. Introduction of computer mapping further improved the quality of this work. Nearly all the maps in the second edition of the atlases were prepared by computer and printed by a modified line printer. Dawson's study (1980) is an example of using such data for a detailed land use study. He demonstrated the great increase in barley growing in Scotland during the period from 1958 to 1977.

Another example is the work done by Wathern *et al* (1988). parish returns were analysed to help explain the recent upland land use and vegetation changes in Clwyd, North

Wales. Relationships between the extent of rough grazing and the number of sheep in the Clwydian Range study area, 1951-1981 were shown clearly.

Robinson's work further demonstrated the feasibility of using data based upon the parish summaries both for its cartographic representation and more complicated statistical analysis. Multi-variate analyses were taken as a framework for studying the expansion of the horticultural industry and the re-alignment of the traditional farming sector (Robinson, 1981).

2.2 Remote Sensing of Land Use and Land Cover

The development of modern technology has enabled substantial progress to be made for data capture, storage, management, manipulation and analysis. The utilisation of computers and remote sensing techniques has probably had the most profound influence on land use/land cover studies.

To begin with, there is a need to address the issue of concepts of land use and land cover. As Anderson *et al* (1976) quoted, "land use refers to, 'man's activities on land which are directly related to the land' (Clawson and Stewart, 1965)," and "land cover, on the other hand, describes, 'the vegetational and artificial constructions covering the land surface' (Burley, 1961)." They also pointed out, "land cover and land use activity are closely related and in many cases have been used interchangeably." Especially when it comes to remote sensing, "image-forming devices do not record activity directly. The remote sensor acquires a response which is based on many characteristics of the land surface, including natural or artificial cover" (Anderson *et al*, 1976). Thus, remotely sensed data are more directly related to land cover than land use. The interpreter has to derive information about land use activities from what is basically information about land cover. Some land use activities cannot even be directly related to the type of land cover. In case this type of information is required, supplemental data have to be employed. Therefore, types of land use and land cover identifiable primarily from remote sensor data have been widely used as the basis for land use/land cover classifications.

2.2.1 Increasing applications

Remote sensing is the science of acquiring and interpreting information about the Earth's environment from measurements made without physical contact. The human eye is the most common remote sensing device, but it is restricted to obtaining local information in the visible part of the spectrum. This capability can be extended by using instruments which can detect and measure selectively filtered radiation from the visible, infra-red and microwave parts of the spectrum.

By installing these instruments in an aircraft, the area observed can be enlarged and an even greater field of view and increased frequency of cover are possible when the sensors are placed in orbit around the Earth.

NRSC (1990:P1)

Some remote sensing techniques have been available and have been utilised for many years. For example, aerial photography has become available since the late 1940s in the UK. To date, the interpretation of aerial photographs has been proven as a well-established methodology for land use and agricultural research and monitoring operations (Birnie *et al*, 1982; Gartner, 1982; Coppock and Kirby, 1987).

The major impetus to studies of land use from photographic imagery arose in war-time. Aerial photography on an operational basis dates from the First World War and almost immediately it changed the nature of warfare - information on the creation of new transport facilities and troop movements gave immediate intelligence of the enemy plans (Rhind and Hudson, 1980:P73). Both German and British forces made intensive and critical use of aerial photographs throughout the Second World War. The complete coverage of the UK in 1946-7 at a scale of 1:10 000 by the Royal Air Force provides a fund of information which is used considerably more extensively than the first (ground) land-use survey (Tarrant, 1974:P92).

Cooke and Harris found in a study of the Isle of Man that it was possible to classify accurately rough grass, dormant bracken, growing gorse, burnt areas and individual tree species in the wooded areas from reflective infra-red imagery (after Tarrant, 1974:P94). Tarrant also concluded from his review that future developments in land use survey would appear to lie in some combination of sample ground studies and more extensive studies based on aerial coverage with multi-band imagery.

Many early successful applications of aerial photograph analysis exist for rural areas where the possibility of rapid areal coverage was of considerable value (Colwell, 1960:P561). Thaman (1974) reviewed many aerial photograph studies and pointed out that the agricultural land use potential of some 600 000 square miles of the Australian Northern Territory had been mapped from aerial photography in a decade.

Another good example is the Land Use and Natural Resource (LUNR) scheme carried out for New York State (Tomlinson *et al*, 1976). That inventory provided a record of land resources which had been evaluated from stereoscopic analysis of 1:24 000 scale, panchromatic aerial photographs of the late 1960s. Some work includes the survey of urban areas in England and Wales, which was undertaken by the DoE and a simple classification geared to aerial photography was employed (Smith *et al*, 1977). In addition, Ilbery and Evans (1989) used aerial photograph and map evidence to examine land loss in a small area on the urban fringe of Birmingham and the results were used to compare the relative accuracy of the Agricultural Census at Parish level.

Some recent national surveys based on the interpretations of aerial photographs include the NCMS conducted by NCC and the Scottish National Survey undertaken by MLURI as detailed in Section 1.1.

Most early examples of the use of aerial photography in land use studies were limited to black and white photographs. Features such as patterns of fields, tone and texture, shape and size of the cropped areas have been increasingly used as aids to interpretation. One of the extensive crop studies by remote sensing is that of the Corn Blight Watch Experiment, 1971 in the USA (MacDonald *et al*, 1973; Barrett and Curtis, 1982:P276). The study concluded that analysis of the data did permit the detection of outbreaks of moderate to severe infection levels although manual photo-interpretation of small scale photographs failed to give adequate detection of Corn Leaf Blight during early stage of infection.

Another role of aerial photography is to provide accurate and detailed ground information to assist the analysis of satellite images with coarser resolution. For example, Clevers (1988) reported that results obtained by using an airborne multi-spectral photographic system proved the validation of the applied procedure for atmospheric correction and radiometric calibration, resulting in information on crops in field trials with greater precision than by conventional field sampling methods.

Whilst aerial photography is finding wider applications and becoming a well-established method, the acquisition of repetitive satellite digital imagery since 1972 has led to further steps in land use survey. It is especially advantageous in providing data collection over a large area in terms of cost efficiency.

The potential application and feasibility of Landsat imagery in studies of land use/land cover and natural resources have been widely explored over the past two decades. Such work in the 1970s mainly involved the utilisation of Landsat MSS data. Computer-aided analysis techniques have been effectively applied for crop identification and area estimation, and adequate accuracy has been achieved (*e.g.* Bauer *et al*, 1978). Aerial photography was also used for selection of the training fields in that study. In another investigation, *a priori* information was used in the image classification to increase the classification accuracy. The use of temporal and spatial features for classification was also discussed (Bauer *et al*, 1979). Among some recent studies, Weaver (1987) used Landsat MSS data to study vegetation succession in upland Scotland. In this, it was recognised that classification based on areas rather than single pixels (*a pixel is the smallest element of an image, also known as a grid cell*) and taking account of relief and the proximity of vegetation boundaries would give better results.

Wyatt *et al* (1988) presented alternative approaches to the classification of upland semi-natural vegetation. They identified the difficulties in automated per-pixel classification techniques using spectral information alone. They also explored knowledge-based classifiers and spectral mixture modelling in the discrimination and classification of upland vegetation with encouraging initial results.

Similarly, Fuller *et al* (1989) assessed the relative merits of Landsat TM data, airborne TM (ATM) data and conventional panchromatic aerial photographs for surveying the ecology and land uses of lowland Britain. They concluded that Landsat TM data are very valuable for extensive field-by-field surveys, and aerial photographs remain the best means of obtaining fine spatial resolution and accurate geometry in remote sensing, though panchromatic photographs lack the radiometric resolution that highlights differences, for example, between grassland and arable farmland. Following this assessment, TM data were further tested by Fuller and Parsell (1990) in a classification of general land use/land cover, especially semi-natural habitats, in an intensively-farmed area of lowland Britain. The work has shown that Landsat TM image classifications can provide accurate cover and distribution data, at the scale of the individual field, for most major land uses. They also pointed out that with some caution, their methods might be adopted for routine operational use.

On the continental scale, the success of the Large Area Crop Inventory Experiment (LACIE) in monitoring crop growth and predicting yield has been noted (*e.g.* Barrett and Curtis, 1982:PP278-282). The LACIE programme was initiated in 1974 to test the feasibility of Landsat remote sensing for the assessment of crop production over several of the most important agricultural regions of the world. It focussed on monitoring wheat production in the selected regions. The algorithms used were reviewed to allow for improved stratification of the inventory region and different acquisitions of data were programmed. The LACIE also revealed that the accuracy of estimate of cropland acreage decreases where field sizes become smaller. An investigation of Landsat data and the yield model response at sub-regional levels showed that drought conditions observable by Landsat were actually reflected by reduced yield estimates in the affected regions. Based on the multi-spectral-temporal pattern of crop characteristics through its growing season, the LACIE method obtained unbiased and precise wheat area estimates over the US Great Plains from classification of Landsat MSS data (MacDonald and Hall, 1980).

Robinove (1979) provided an example of similar work in Australia with a land system mapping experiment using Landsat images in southwestern Queensland, where conventional land system mapping had been carried out in 1975 and 1976. The project attempted to relate the description of land mapping by Landsat imagery to land system mapping by the well established Australian methods. The significance of this work was that Integrated Terrain Mapping combined several terrain features into each map unit which, in many cases, was more directly related to uses of the land and to methods of land management than the single feature alone. Landsat MSS data have also been used by Kelly and Hill (1987) to update existing climax cover maps for an area on the fringe of the wheat belt in southern Queensland. Other examples in Australia include the assessment and monitoring of rangeland using calibrated Landsat data. Indices of 'cover', which is a composite variable comprising all the percentage cover of living and non-living plant material, were derived and used to assess and monitor the behaviour of individual rangeland types and pastoral properties over the 1981-1984 period. The results showed the feasibility of using Landsat data for operational range assessment and monitoring in the arid rangeland of Australia (Graetz *et al*, 1988). Also, Dawbin and Evans (1988) described digital crop classification techniques developed for Australian conditions. Supervised maximum likelihood classifications were applied to Landsat data from five dates. Despite the confusion between wheat and barley because of the overlap of crop calendars, the classification technique for the predictions of winter crops versus non-winter crops has produced adequate accuracy and proved its applicability.

In Europe, only a few large experiments on land use/land cover mapping have been carried out and the possibilities of remote sensing-based agricultural inventories were then studied at national level only in Italy and France (Hill and Megier, 1988). Hill and Megier (1988) presented their work on the land use inventory and thematic mapping of a region in southern France by means of automatic classification techniques for the defined eight classes:

1). Vineyards

2). Orchards

3). Other cultivation

4). Permanent grasslands

5). Shrublands and moorlands

6). Forests

7). Water and

8). Built-up areas.

Their results showed that knowledge of agricultural practices in the area was mandatory for the success of the whole process. The importance of land cover definitions was also stressed in their conclusion.

One of the major applications of remotely-sensed data obtained from Earth-orbiting satellites is change detection. But care must be taken in accounting for radiance changes due to different factors and the effect of geometric registration of images on digital change detection techniques. In an article by Singh (1989), a variety of procedures for change detection based on comparison of multi-temporal digital remote sensing data have been reviewed and evaluated. The digital change detection techniques analysed included: univariate image differencing; image regression; image ratioing; vegetation index differencing; principal components analysis; post-classification comparison; direct multidate classification; change vector analysis; background subtraction and other methods. The results indicated that different procedures of change detection sometimes produced different maps of change even in the same environment. He appreciated that "when a difference in radiance values between two dates is taken as an indicator of changes, the difference may be due to several factors (Riordan, 1980) such as actual changes in land cover (signal), differences in illumination, differences in atmospheric conditions, differences in sensor calibration, differences in ground moisture conditions and differences in the registration of the two images." Thus, models should be developed to "distinguish useful temporal variation, *i.e.*, changes in land cover, from variation arising due to external factors such as atmospheric conditions, moisture conditions, Sun angle differences and differences in sensor calibration." Also, he stressed the dependence of those techniques upon the accuracy of the geometric registration of images. "So there is a need to explore the possibility of developing digital change detection techniques which require less precise registration of images or which bypass the registration process."

The post-classification comparison method was used in this study for change detection. As pointed out by Singh (1989), it requires the comparison of independently produced classified images. This method "holds promise because data from two dates are separately classified, thereby minimizing the problem of normalizing for atmospheric and sensor differences between two dates. The method also bypasses the problem of getting accurate registration of multidate images." "However, if one considers the land cover classification generated from a single date of Landsat data, it is not difficult to see that the change map product of Landsat classifications is likely to exhibit accuracies similar to the product of multiplying accuracies of each individual classification. Hence it can produce a large number of erroneous change indications since an error on either date gives a false indication of change."

In sum, many studies have demonstrated the great potential of remote sensing applications in land use/land cover inventories. Increased value and wider applications are being explored world-wide. Often, a systematic approach to remote sensing applications is needed to meet the requirements of a defined project. "In practice, many systems are hybrid, in the sense that they rely on more than one technique, e.g., the interpretation of both aerial photographs and satellite imagery requires ground survey to verify the interpretations/classifications offered...Such combination may involve either different methods in combination at the same time,... or the use of different methods at different times,...or to employ all possible sources in order to take advantage of their respective strengths and to minimise the handicaps of their respective weaknesses" (Coppock and Kirby, 1987:P45).

2.2.2 Continuous improvements

(1) Development of classification schemes

Independent work done by different agencies at various governmental levels has often led to duplication of efforts. Major problems were present, especially in the application and interpretation of the existing data due to changes in definitions of categories and data collection methods by source agencies. Thus, there is a need for standardised land use and land cover data, and this demand can only increase as efforts continue to assess and manage areas of critical concern for environmental and other problems. Moreover, "recent developments in data processing and remote sensing technology make the need for similar cooperation in land use inventories even more evident and more pressing. Development and acceptance of a system for classifying land use data obtained primarily by use of remote sensing techniques, but reasonably compatible with existing classification systems, are the urgently needed first steps" (Anderson *et al*, 1976). Therefore, a lot of work has been carried out on the development of land use/land cover classification systems in order to make use of the new data sources objectively and consistently, and thus to adequately inventory land resources. They also represent one major part of the progress in land use studies.

To design a classification system, the first need is to define the types of land use and land cover categories. One of the most important approaches is the framework of a national land use and land cover classification system, as established by the U.S. Geological Survey (USGS) for use with remote sensing data (Anderson *et al*, 1976). Multi-level land use and land cover classification systems have been developed because different sensors provide data at different resolutions depending on the altitude and scale. "The size of the minimum area which can be depicted as being in any particular land use category depends particularly on the scale and resolution of the original remote sensor data or other data source from which the land use is identified and interpreted. It also depends on the scale of data compilation as well as the final scale of the presentation of land use information. In some cases, land uses can not be identified with the level of accuracy approaching the size of the smallest unit mappable, while in others, specific land uses can be identified which are too small to be mapped" (Anderson *et al*, 1976:P5). In the USGS classification system, the first and second levels are receptive to data from satellite and aircraft remote sensors. It is intentionally left open-ended to give flexibility in more detailed land use classification at the third and fourth levels in order to meet the particular needs of a study, and meanwhile remain compatible with each other and the national system.

This classification system has also been practised in reality. In the National Petroleum Reserve project in Alaska (NPRA), the land cover classes followed the classification system being used in the USGS land use and land cover mapping program. It has shown that Level I categories of the aforementioned USGS classification system are applicable to the generalised NPRA classes. But Level II categories were modified to satisfy special requirements (Morrissey and Ennis, 1981).

The definition of land cover classes and its proper use are probably the most important pre-requisite for regional land use/land cover mapping via the use of remote sensing techniques. The next step is to exploit the full potential of the utility of remote sensing data by extracting as much information as possible.

(2) Improved classification methods

Interpretation of aerial photographs has been well developed and has become a routine technique in land use/land cover analysis and mapping. Low and medium altitude aerial photographs not only provide data for multi-level land use/land cover classification, but also they are an important data source for selection of certain training and testing fields in Landsat data analysis. These photographs can be interpreted and combined with ground survey data to provide selected land use/land cover information. With the new technology of video cameras and computers, accurate measurements of changes can be achieved quickly and the "answers" can be recorded in hardcopy, and transferred to maps.

Since the availability of Landsat digital imagery, continuous efforts have been made to demonstrate its utility in developing land use/land cover and crop area statistics as well as exploiting its full potential by extracting as much information as possible. Various kinds of image enhancing and analysing techniques along with the incorporation of ancillary data have been used to improve the level of land use/land cover information available from the imagery.

The most popular classifiers in the commonly-used image processing systems are the parallelpiped classifier, the minimum distance classifier and the maximum likelihood classifier. Details of definitions of these classifiers can be found in Chapter 3. It is generally believed that the maximum likelihood classifier gives the best classification result (Lillesand and Kiefer, 1987:PP675-677). However, Belward and Hoyos (1987) reported that similar levels of classification accuracy were obtained using maximum likelihood classification and a supervised binary decision tree for crop classification from multi-temporal Landsat MSS data. The binary decision tree was manually designed from consideration of coincident spectral plots. Numerical limits for best class separation were established for each spectral band. A series of 1-bit masks were created corresponding to the limits set by the decision tree. Each band was then multiplied by the masks in a hierarchical fashion until each individual cover class was partitioned. The ease of training and computational simplicity of the binary decision tree actually suggested a viable alternative to the maximum likelihood for the analysis of data-sets with high dimensionality. However, it is easy to appreciate reservations on the application and benefits of the binary decision tree. While the maximum likelihood classification can be implemented from most existing software, the decision tree has to be implemented as a series of masking and multiplication steps, rather than a single operation. Also, setting numerical limits for each band through examination of the coincident spectral plots is by no means an easy job. It may be rather time consuming too, especially when an integrated classification is required. Moreover, the training set has to be selected for each classification as the spectral characteristics vary for different areas or over different time periods. Other stratified or layered classifiers have also been utilised in practice to simplify classification computations while maintaining classification accuracy (Lillesand and Kiefer, 1987:P678).

Among the general criteria proposed by Anderson *et al* (1976) for developing the classification system is that the minimum level of interpretation accuracy in identifying land use and land cover categories from remote sensing data should be at least 85 per cent. To achieve certain user acceptance, much work has been involved in improving classification accuracy. For example, Cushnie (1984) reported that the separability of land cover classes could be improved by spatially filtering the Landsat TM data prior to the classification, which modifies the values for each pixel by considering the pixel values that surround it. Better results were obtained by combining filtered TM data with non-filtered TM data under the assumption that the degraded data by using an averaging filter and a median filter would smooth out the internal variation or scene noise while the inclusion of data at full resolution would retain some boundary detail.

Similarly, post-classification techniques have also been applied to eliminate misclassifications arising from scene noise effects, such as majority mode filtering (*e.g.*, Mather, 1987; Schowengerdt, 1983; Townsend, 1986). In a study by Williams (1987), both pre-classification median filtering and post-classification majority mode filtering were used on an upland vegetation classification performance in Snowdonia using TM data. The highest correspondence was achieved with the maximum level of both pre- and post-classification filtration, using a 7 x 7 kernel in each operation.

Apart from image filtering, other strategies have been adopted to improve classification accuracy, such as inclusion of ancillary data (*e.g.*, digitised maps and terrain data) in various ways for the classification of Landsat data (Hutchinson, 1982). In addition, a Digital Terrain Model (DTM) of the area could be used for the improved classification of a mountainous terrain affected by the non-uniform illumination of the landscape, where the DTM can work as a background for displaying thematic information or for combining relief data with thematic data such as soils, land use or vegetation (Burrough, 1986:P39). "Even with a DTM, it would still be necessary to model the detailed interactions between each ground cover type with incident illumination to produce an effective correction" (Williams, 1987). Similarly, the use of textural pattern in the imagery, and ancillary data such as relief or the nature of surrounding vegetation, will improve the level of information available from the imagery (Arai *et al*, 1987). At present, this is often derived by visual analysis of the imagery and the use of ancillary map and photographic information. In the longer term, an automated approach can be resumed when image processing algorithms and GIS structures are sufficiently well developed (Weaver, 1987). In addition, classification accuracy could be increased if a contextual classifier was used, which considered the spatial correlation between class of a pixel and those of its neighbouring pixels, instead of looking at a single pixel only (NERC, 1987; Gurney, 1981 & 1983). Such work has also been supported by statisticians, such as developing techniques to handle the highly-structured data of images, mainly involved in statistical pattern recognition (*e.g.* Ripley, 1985), and the statistical analysis of noisy pictures by proposing better methods of reconstruction of the true scene (*e.g.* Besag, 1986).

Remote sensing analysis is moving from exploiting its potential towards an operational application. Expert systems, which represent expert knowledge by frames, are offering further prospects for progressive automatic analysis of remote sensing data. Work of this kind often involves the use of GIS. For example, Wu *et al* (1988) presented a model-based remotely-sensed image interpretation expert system, embedded in a knowledge-based GIS. The results were claimed to have shown a significant improvement in image analysis. Also, segmentation of remote sensing imagery by a split-and-merge process has shown an increased classification accuracy (Cross *et al*, 1988). In that study, images were segmented into regions of homogeneous tone and texture where possible. Then the segmented image was classified using a region classifier for regions and the normal per-pixel classifier for single pixels in areas of inhomogeneity. Furthermore, Corr *et al* (1989) established a system for automatic knowledge-based segmentation of remote sensing images of land. With improved accuracies of segmentation and subsequent classification, they revealed a way forward to meet the need for efficient automatic analysis procedures.

2.3 Integration of Remote Sensing and GIS

"A GIS is a method of storing and retrieving data which are held in a structured form, have locational identifiers and can therefore be manipulated and mapped in a variety of ways" (Young, 1986b:P4). The first GIS was developed in Canada in the mid-1960s (Tomlinson, 1984). The technical success achieved in that period has underpinned the development of GIS to date.

In the past, most analysis and interpretation of land use data have been manually based. However, important developments in GIS have brought about a variety of facilities for carrying out these functions by automated means (Rhind and Hudson, 1980:PP124-125). GIS provides facilities for data capture, manipulation, analysis and representation of results in cartographic and statistical forms with an emphasis on preserving and utilising the inherent characteristics of spatial data. Rapid advances in computer technology in terms of interactive capability and lowered computational costs have increased users' ability to interact with GIS processes.

Meanwhile, remote sensing generates a wide range of data which have the advantages of being accurate, timely, comprehensive and readily retrievable. Thus, it has introduced a new way for land data collection, mainly with photographic and digital imagery data. Handling of the large volumes of data so collected has necessitated using a computer system. Fortunately, technological developments in the handling of spatial data by computer have met this need. The application of computer-aided systems for analysing spatial data has resulted in the advance of more comprehensive classification systems which have been designed for use with remote sensing data (e.g. Anderson *et al*, 1976). Moreover, the substantial significance of the integration of remote sensing and GIS techniques has been recognized increasingly (*e.g.* Arnberg, 1981; Estes, 1984). For remote sensing data to be most useful, they must be combined with other data types. As demonstrated in the last section, improvements in digital classification of Landsat data can be achieved through the incorporation of ancillary data, which are usually map-based, *e.g.*, the Ordnance Survey topographic maps, soil maps and maps of land capability for agriculture. These maps can be digitised and stored in the database and then transferred to the image processing system as auxiliary data in image analysis or for further use by overlaying different data contents. Remote sensing can update GIS data planes while GIS can provide for the efficient use of the ancillary data required by remote sensing analysis such as entering new features into classification of satellite images.

As summarised by Young (1986b) in Figure 2.1, the main components and functions of an idealised GIS should include (a) input and collection, (b) storage and retrieval, (c) manipulation and analysis and (d) output or reporting of data. Its interaction with external packages or other GIS in a multiple flow of information is also stressed and expressed in the figure. If the figure is to be updated, perhaps a box of "error assessment" or "quality assurance" should be added as is often required to couple any remote sensing and GIS research. It is particularly important if the data are to be linked to external models.

Figure 2.2 describes the possible steps in a GIS data handling routine. Developments in GIS and remote sensing have brought a new prospect for land use studies. As pointed out by Estes (1984), "the realisation of the importance of information systems is a TREND." Much work has shown the useful application of remote sensing and GIS in establishing land use/land cover information systems. Some examples in previous studies are mentioned as follows.

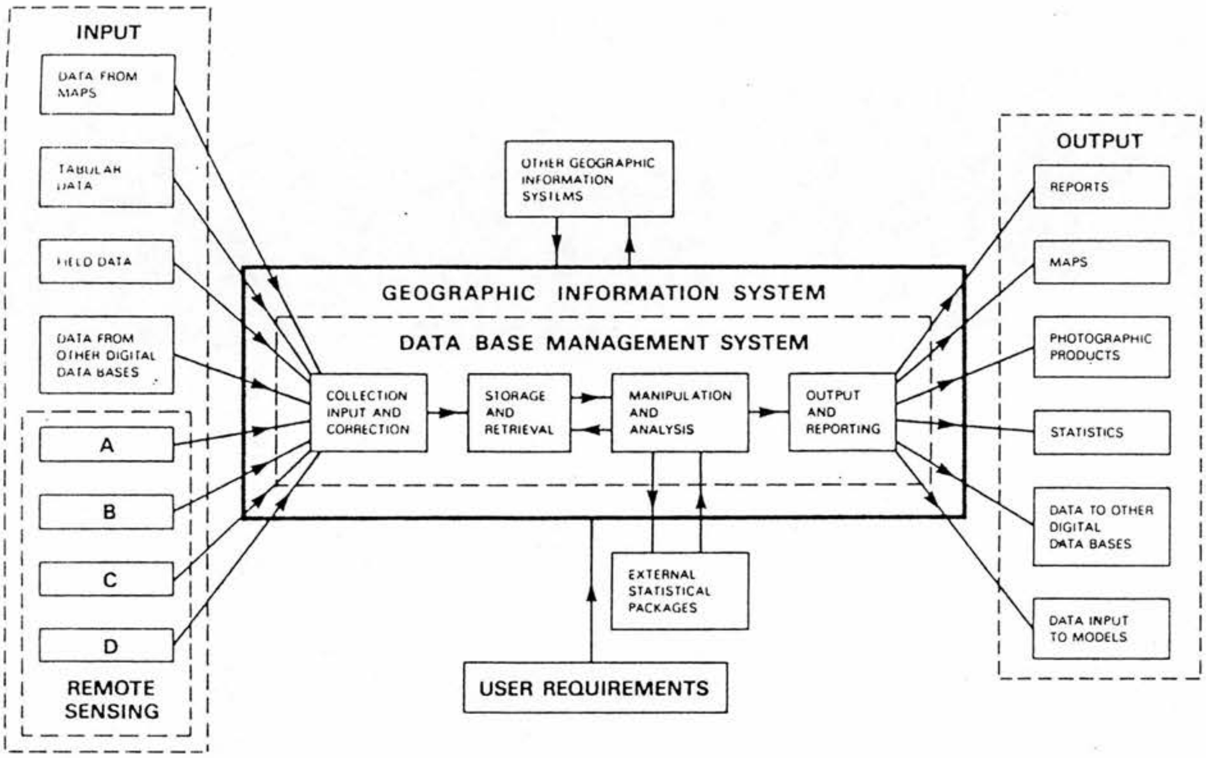

Figure 2.1 Main components and functions of an idealised GIS for resource planning and management that is capable of integrating and using remotely sensed data. A -- digital data from satellites; B -- data from aerial photographs and photographs from space; C -- frames from airborne video reconnaissance; D -- data from sensors which are either fixed or mobile and are located either near the ground or on ground platforms (after Young, 1986b:P5).

The Rural Land Use Information System (RLUIS) Project (1978-1980), funded by the Scottish Department of Development and the Department of Environment, was an important technical pilot project. It considered the major data sources on rural land use in Scotland and demonstrated the feasibility of digitising data on topography, economic and social conditions and development pressures. It also evaluated the adequacy and compatibility of computer equipment (hardware) and analysis programs (software), *e.g.* GIMMS. The findings of the project confirmed the need for the development of land use information systems to aid rational solutions to increasingly complex planning and environmental problems (Scottish Office, 1980). The project analyses also amply showed the benefits, usefulness and flexibility of computer handling of data and particularly the

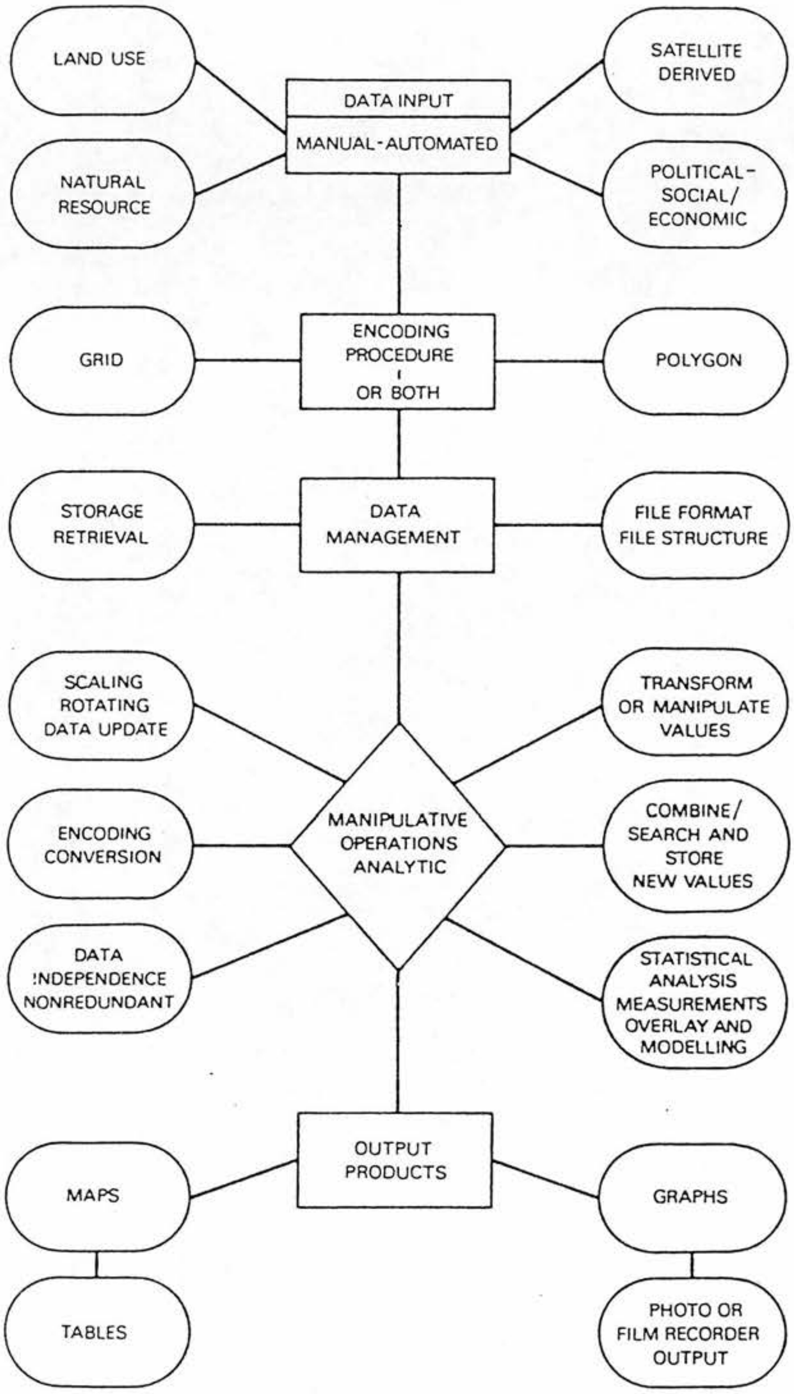

Figure 2.2 Possible steps in a GIS data handling routine (after Campbell, 1982. See also Young, 1986b:P13).

high quality of the digital map output on an automated plotter. It was potentially of great importance for current Scottish land use studies as well as in providing guidance for future studies. However, the Pilot Project was a particular combination of available facilities, software and expertise. There were difficulties in establishing an enlarged system. Selectivity and coordination of the data bank would be vital. The costs of storage of digital data and new software required form another problem. What is more, RLUIS ceased to exist when its sponsoring committee was disbanded in 1981 (Coppock and Kirby, 1987:P55).

Hogg and Stuart (1987) employed a pilot GIS to accept classified Landsat TM and other information from digital maps in a relational database management system. They demonstrated the potential of using classified images together with ancillary data for analysis and management of natural resources. Birnie (1987) reviewed several themes relating to research in the development of raster data-based GIS. In that review, some different uses of map data, especially in relation to satellite imagery, were illustrated and the potential for increasingly sophisticated uses within knowledge-based systems were pointed out. It was realised that the success of these techniques was dependent on their perceived value and in particular on their applicability in a wider range of management problems.

Meanwhile, application of Landsat data together with GIS for land use/land cover study and environmental monitoring has been more popular in Canada, USA and Australia, where the large land areas enable it to be more economically viable.

The Geographical Information Retrieval and Analysis System (GIRAS) has been designed and developed by the US Geological Survey to accept digitiser input, provide comprehensive editing facilities, produce cartographic and statistical output, permit retrieval and analysis of data, and exercise database management tasks (Mitchell *et al*, 1977). This system has incorporated facilities for gridding polygon data to make it compatible with grid-based data sources. That is, the transformation between vector and raster data has been realised. System development was also focussed upon an interactive database to enable immediate retrieval and display of map information. The editing and output procedures were operational in the system.

Similarly, the Canada Land Data System (CLDS), which was originally designed to allow storage, retrieval and manipulation of Canada Land Information Data in southern Canada, has proved to be operationally feasible for any geographically mapped data in the country (Rubec, 1980). Various kinds of databases, such as land capability for agriculture, forestry or recreation, watersheds and soil types, are available in CLDS, which plays an important role in land use studies. In addition, interpretation of selected Landsat images and overlay of thematic maps into the CLDS can be used in conjunction to generate land data summaries for "Land Use Sections", which allow identification and description of ecologically distinct land use sections for large areas of Canada.

In a recent study, Wright and Morrice (1988) examined the use of multi-temporal Landsat satellite radiance values to classify the potato crop. The study integrated the spatial distribution database with soil and potential water deficit data to generate statistical information on the proportion of the potato crop growing on the drought susceptible soils. The results showed that the area and individual locations identified were comparable to DAFS statistical returns. The use of a geographic database provided typical information for potato production.

Also, Quarmby and Cushnie (1989) reported from their study that remotely-sensed data could provide planners with visually impacting material and a method of monitoring the urban fringe on medium-term time scales using change detection procedures. The addition of other sources of geographical information can be used to improve the accuracy of the change detection and to enhance the interpretation of images. This facility enables planners to make greater use of remotely-sensed data.

Another important aspect brought about by the integration of remote sensing and GIS is the improved presentation of the analytical results and end products. This is an integral part of land use study. Computer-aided cartography is becoming a widely used tool in the presentation of spatially referenced data. One example is the mapping of regional statistical data by using programs such as CAMAP or GIMMS, which were both developed at the University of Edinburgh. This enabled the quantitative values of regional statistical data, such as parish summaries, to be further appreciated.

The mapping side of remote sensing analysis is an important input to GIS or any other system, although it is not the only input. Computers are now being recognised to have an increasingly important role in fulfilling this purpose. They can store and deal quickly with large quantities of two and three dimensional data, undertake repetitive tasks, such as drawing, and replace manual procedures with a high degree of precision when undertaking complex calculations (Evans and Turnbull, 1987). Integrated use of remotely sensed data in applications has also been one of the current research foci in land use studies. It has been shown that output from image processing can be transferred into the mapping systems as a new thematic overlay for plotting to get high quality digital map output or for further analysis (NERC, 1987). In 1982, Birnie *et al* recognised that an operational methodology for digital image processing and automated mapping marked the union of photogrammetry and remote sensing.

The difference between GIS and systems for computer-assisted cartography is the provision of transformation capabilities (Burrough, 1986). Although some of them, such as those for data cleaning or updating, or for changing scales or projections, are common to both GIS and computer-assisted cartography, GIS offers a much larger range of analysis capabilities to operate on the topology or spatial aspects of geographical data and on the non-spatial attributes combined, in order to be able to answer particular queries. The distinction between automated cartography and GIS is significant. In automated cartography, the non-spatial data relate mainly to colour, line type and symbolism whilst in GIS, the non-spatial data may record land use, soil properties, ownership, and vegetation types (Burrough, 1986). In another word, the main distinction is that a GIS can relate a number of types of data whereas automated cartography simply maps or draws.

Usually the output product generation for land use studies involves geographic registration to map base, digital mosaicking and acreage summaries (Morrissey and Ennis, 1981). In general, the draughting stage of the cartographic process has been automated so far. The main problems exist in map design and automation of the generalisation process. In the USGS classification system (Anderson *et al*, 1976), a scheme of colour coding was employed in order to provide a systematic and uniform approach to the presentation of land use and land cover information in map format. In that scheme, Level I land uses were colour coded while Level II land uses were presented using the two-digit numeral appropriate to the land use category. A numerical system with the number of digits equalling the level of categorisation formed a flexible classification system that permitted continuation to Level III and IV or beyond.

With developments of mapping systems and the standardisation of data input and output, land use analyses have been brought to a new era when automatic analysis of changes in land use by overlaying classification results through different time periods has become possible.

2.4 Current Trends and Areas of Weakness

As noted by Dowman (1990), current trends in research on remote sensing and GIS can be summarised as follows. First, global monitoring of land and sea requires an establishment of global data-sets. Then comes the automation of approaches aimed at faster data processing. Wider application of GIS is another important trend to meet requirements of data integration. Last, validation of data ensures the quality control of any research. Validation exercises are being widely practised in all kinds of global monitoring projects and will be continually practised in the future. Meanwhile, developments of new sensors are taking into account the need for stereo data with three dimensional viewing.

With respect to land use studies, similar trends can be recognised. It is implicit that the collection and processing of environmental data leads to improvements in the environmental management and control, provided that the data are sufficiently reliable and error-free. Regarding the current weakness of remote sensing utilisation, it is often accused as being technology-driven rather than application-led. However, Birnie (1988) argued this situation was somehow inevitable: "we have to live within the technological limitations, which is not quite the same as being 'technology-driven'. The trick is to know what is, and what is not possible, within the limits of current technology." He also addressed the importance of a conceptual framework in a situation where both the technical possibilities and the potential applications were wide ranging, as well as the question of how relevant information could be extracted and used specifically in the context of regional planning. Careful conclusions were drawn that there was a place for remote sensing in local resource planning, but it was important to use the techniques in a systematic and appropriate manner. Indeed, development of technology in remote sensing is moving enormously quickly. One question arising is the link between different stages in the development as well as the integration of different data drawn from different sensors. With respect to the relationship between remote sensing and conventional land use data applications, it is not very likely for one to replicate or replace another completely. In fact, integration of different data sources, techniques and approaches is an urgently required step for a timely and complete study of regional land use. An encouraging sign of progress though, is that development of remote sensing along with GIS is moving from experimental science to routine operational applications.

2.5 Summary

Conventional statistical data have provided valuable data sources with their wide coverage and continuity over long historical periods. Among various land use data from list and text, the British national agricultural statistics, which have been collected on an annual basis since 1866, have been extensively used for reconstruction of agricultural land use patterns and indication of rates of change in land use. Introduction of computer mapping further improved the quality and efficiency of this kind of work. The use of such statistical data is especially significant for a long term retrospective study when other data sources were not available or were inconsistent over the required period. What should be noted here is that 'statistics' are not necessarily totally accurate because of the way in which data are held or generalised to maintain confidentiality at farm level.

Developments of modern technology in computing systems and remote sensing techniques have given impetus to various aspects of land use studies. This has been shown both in the improvements of data collection and the systematic handling of spatial data. Interpretation of aerial photography has demonstrated its wide applications and is becoming a well-established method. Features such as patterns of fields, tone and texture, shape and size of the cropped areas have been increasingly used as aids to interpretation. Aerial photographs have been the best means of obtaining fine resolution and accurate geometry in remote sensing. On the other hand, satellite digital imagery has shown its capability for providing data collection in land use survey over a large area with increased cost efficiency. Landsat TM imagery has demonstrated its value for extensive field-by-field surveys. Development of imagery classification schemes and improved classification methods have further enhanced its potential towards an operational application.

GIS has had a profound influence upon land use analyses. Important developments in GIS have brought about a variety of facilities for carrying out analysis and interpretation of land use data by automated means. The integration of remote sensing and GIS has enhanced the potential of each technique. Remote sensing analysis can update GIS data planes while GIS provides for the efficient use of the ancillary data required by remote sensing analysis. Information extraction from remotely sensed data through the use of a knowledge-based GIS will form part of an automated approach along with the improvement of classification accuracy and automated map generation.

CHAPTER III

METHODOLOGY

In order to explain more fully the methods that were developed in this research, it is convenient to divide the work into three parts: (a) selection of the study area, (b) basic data acquisition, and (c) the monitoring of changes in land use/land cover. Figure 3.1 shows the major data sources and how they are used to monitor changes in land use/land cover. The inter-relationships between different elements are also demonstrated in the flow diagram.

3.1 The Study Area

The initial step of the monitoring process was the selection of the study area. The Lammermuir Hills and adjacent lowlands in South-East Scotland were chosen in this case for the following reasons. Firstly, this area covers different land use zones, from lowland arable farming to mixed farming of livestock and crops in the upland fringe area, and to rough grazing on hill farms. Secondly, this area has experienced such changes as afforestation of former moorland, conversion of rough pasture to improved grassland and expansion of arable land towards the upland over the past four decades (Eadie, 1984). Thirdly, the choice of study area was based on the availability of a range of data for the study of changes in land use. These data include agricultural statistics, aerial photographs, Landsat digital images and other cartographic or record data as explained in the following sections. Finally, the easy access to the area for ground truth work also influenced this choice of a study area.

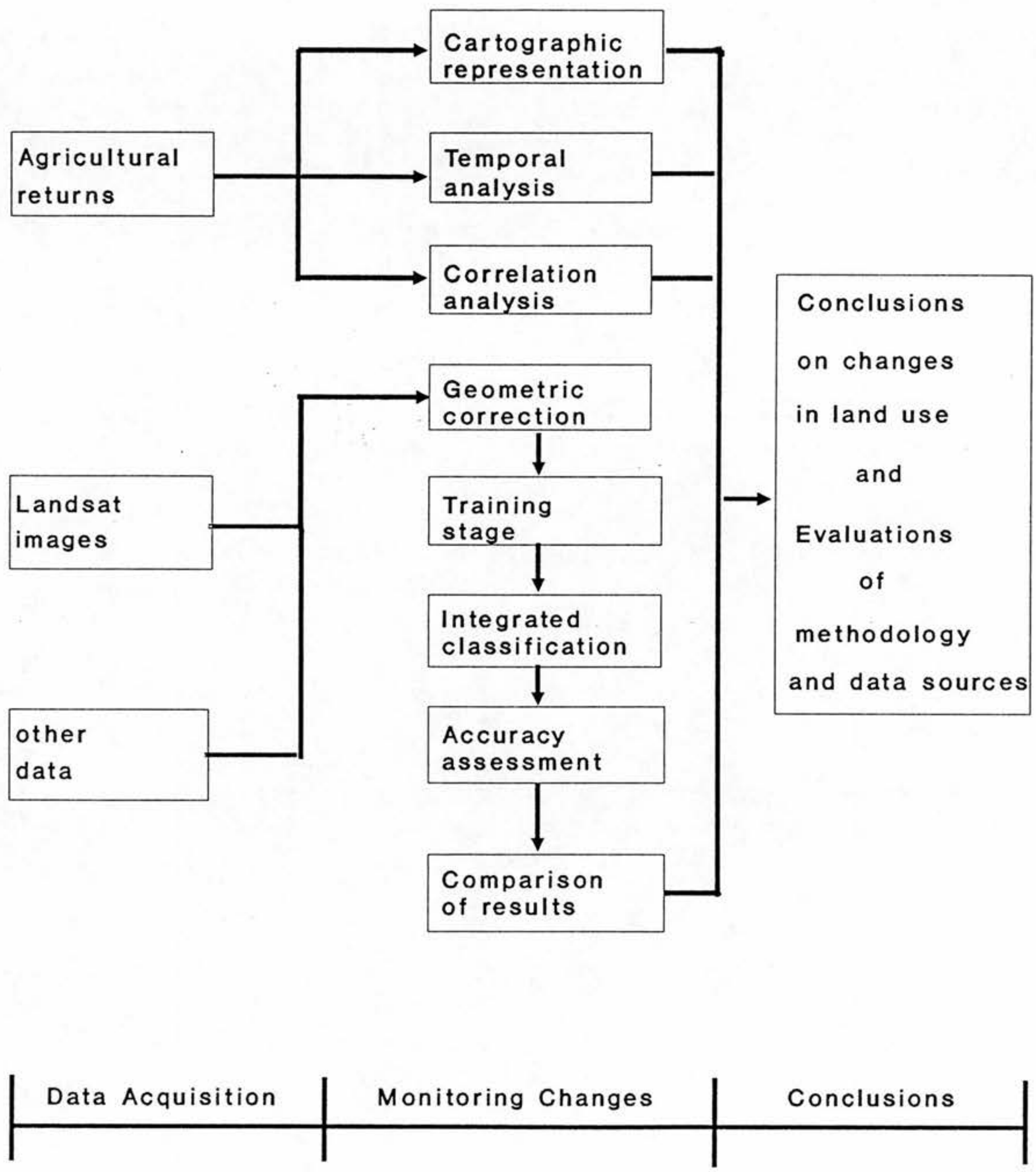

Figure 3.1 Flow diagram showing contents of the adopted methodology

The area selected for study extends into three Scottish districts: East Lothian, Berwickshire and Mid-Lothian (Figure 3.2). It embraces sixty-one parishes covering an area of approximately 1700 square kilometres. The Lammermuir Hills, which are largely open and treeless and mainly under heather moors, are situated in the centre of the study area. The soils of the area are closely related to altitude and slope, with Brown Forest Soils occurring below 250 to 300 metres on very steep land, the mid-slopes carrying Humus-iron Podzols, and, with increasing altitude, peaty podzols occupying many upper slopes and hill summits below 600 metres. Above 600 metres, the soils are transitional over a broad zone to sub-alpine soils on the high mountains, a gradual change over 75 metres or so of altitude (Bown and Shipley, 1982).

The pattern of vegetation on the Hills is related to the distribution of soils in the area and is modified by land management practices such as grazing and heather burning. The plant communities are an expression of the range in the area's geology, soils, climate, landforms and land use. For instance, the dwarf shrub heaths and semi-natural rough grasslands occur mostly on podzolic soils and form a major element of landscapes which have been under intense grazing management for many years.

Previous studies (*e.g.*, Stamp, 1941 and Parry, 1973) recognise three major types of land use in South-East Scotland (Figure 3.3), which can be distinguished by the factors of elevation and soil quality. First, the core moorlands in the central Hills are characterised by the relative high elevation and a highly dissected area with steep slopes and valleys. Hill farms, with their extensive acreage of rough pastures, have very small areas of arable land or permanent pasture. Sheep breeding is almost the sole concern of the hill farmer. Second, the drier upland zone, amenable to agricultural improvement, is represented by gentle slopes. Livestock rearing with arable farming is common on the grassland. The arable acreage is primarily on the lowland farms which are mainly in the East Lothian Plain and the Berwickshire Merse. Cereal growing for sale is an important feature in the farm economy of the lowlands where root crops are grown to provide food for stock, with sheep rearing being the most important concern. On the gradual transition from the lowlands to the uplands, soils are more favourable for growing root crops and such cereals as barley and oats.

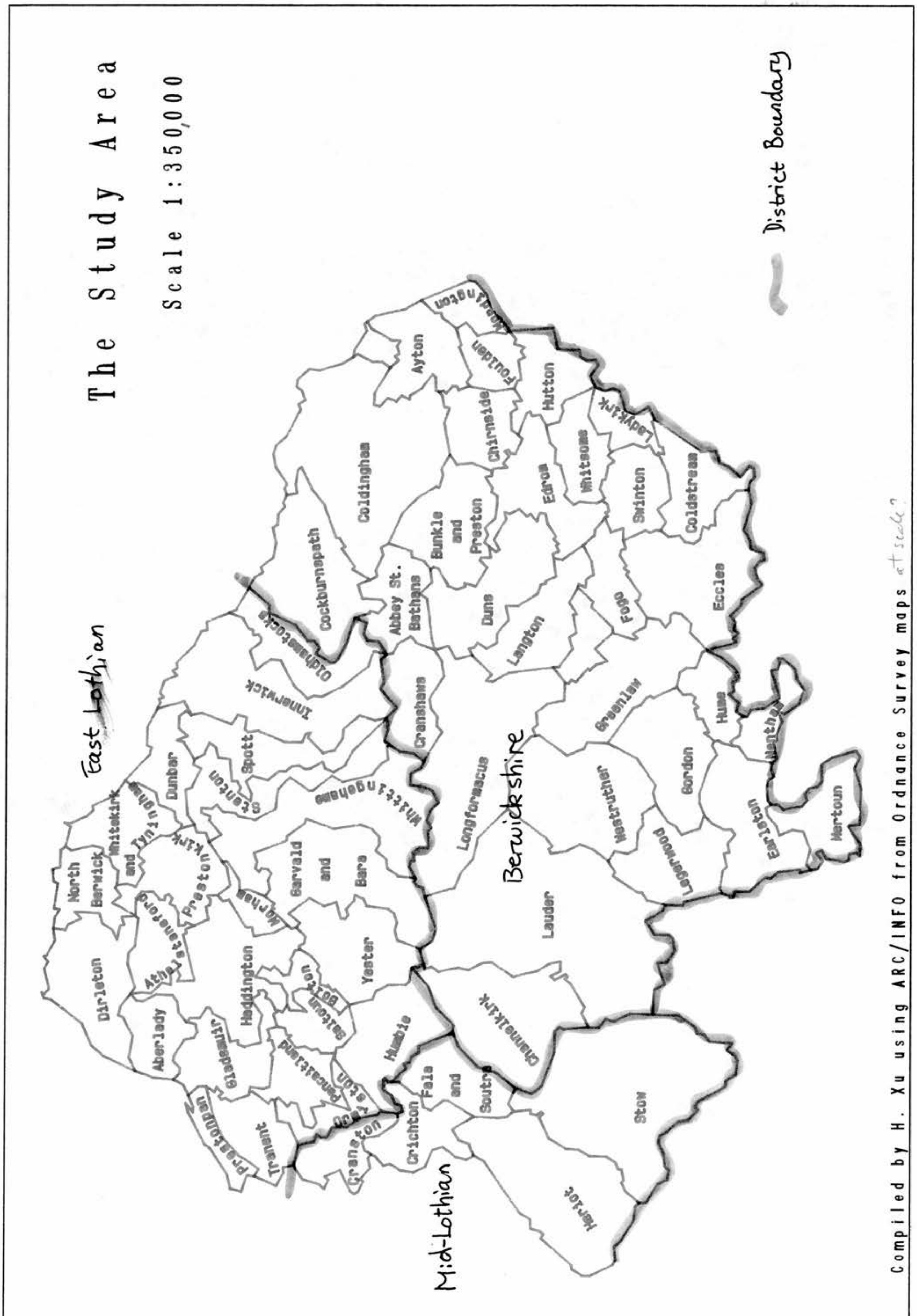

Figure 3.2 The selected sixty-one parishes in East Lothian, Berwickshire and Mid-Lothian for the analysis of the parish summaries

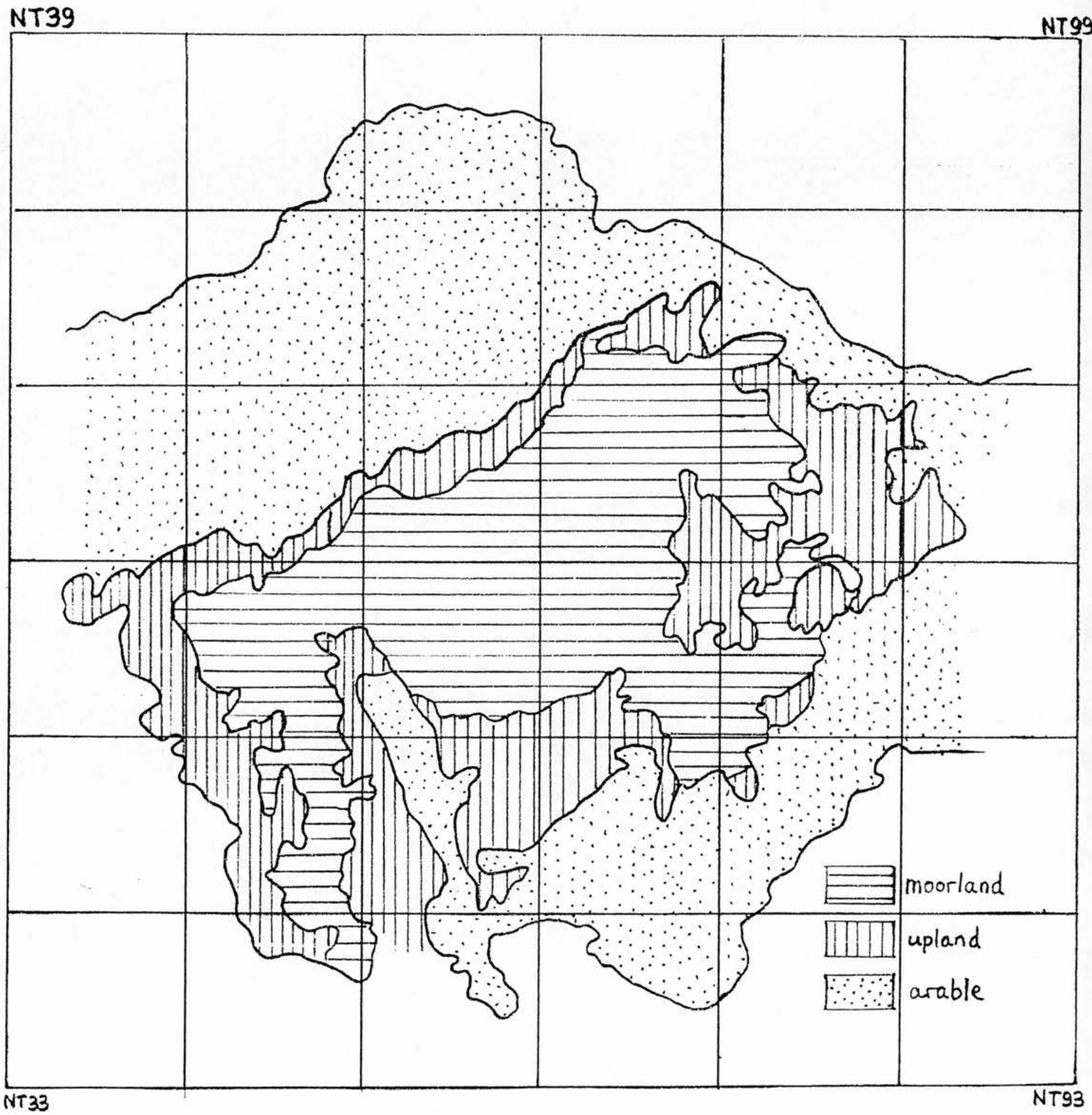

Figure 3.3 Three major types of land use in South-East Scotland.
Source: Ordnance Survey Soil map and Parry (1973).

Forming the north-eastern extremity of the Southern Uplands and flanked by the East Lothian Plain and the Berwickshire Merse, the study area has an obvious physical unity that has promoted a common history. However, the historical pattern of regional land use has been modified continuously. For example, some areas of heather moorland have been recognised as subject to severe pressures as a consequence of a long history of sheep farming and the increasing pasture reclamation and recent afforestation.

Therefore, there is a need to assess and update information on the distribution and dynamics of land use in the area. The results of this study have demonstrated that the Lammermuir Hills and adjacent lowlands have been a good choice as a test area meeting the requirements of the research.

3.2 Data Acquisition

The primary data sources were agricultural statistics, Landsat images, aerial photographs and additional cartographic data.

3.2.1 The agricultural returns

(1) Collection of the statistics

Agricultural censuses are commonly presented as statistics aggregated for a predetermined geographical unit and they report the state of agriculture in the country at a single time in the year. In the U.K., the agricultural census takes the form of the annual agricultural returns provided by individual farmers and then consolidated into parish and county summaries. Although the original returns with details for each farm are destroyed, the parish or county summaries provide a continuous, though variable, annual record since their inception in 1866. They comprise facts about the nature of farms as well as more generally useful information regarding the rearing of livestock and the production of crops. Items included in the census are number of livestock, size of farm, labour force, acreage farmed, and types and acreages of crops grown within each parish. As summarised by Tarrant (1974:P71), the returns in recent years have followed a broad division into three sections. Firstly, they are relevant to land use within the farms, *e.g.*, area devoted to each crop including rough grazing, woodland and other land that is not in agricultural use. The second concerns the agricultural animals on the farm, *e.g.*, cattle, pigs, sheep and poultry. Thirdly, they list the number, sex and age groups of the workers on the farms, indicating whether their employment is whole-time, part-time or seasonal.

Examples of the questionnaire sent to farmers and the computer layout of the returns can be referred to in Appendix 1.

(2) Appropriateness, reliability and application of the returns

The information provided in the agricultural returns has been used in the past for studies as diverse as the effect of radiation on livestock, and the impact of country parks on agriculture. They are made available by the Ministry of Agriculture to other government departments and often form the basis of the planning and provision of many government services, such as using the returns to examine land loss in urban fringe localities so as to see the effect of Green Belt policy (Ilbery and Evans, 1989).

The annual agricultural returns consolidated into parish and county summaries have also been used in numerous studies of agricultural changes, either in conjunction with source material on individual farms and estates or as the prime database (Robinson, 1988). The long term continuity and the nationwide coverage of the returns have made them an attractive data source. As Coppock (1970) pointed out, "the acreage returns must play a major part in the regional studies of agricultural change in Great Britain in the period since 1866". Indeed, they have been the chief source of statistical information for studying agricultural activity in the U.K. during the past one hundred years. They have become an important data source for providing information on general characteristics of regional land use and can be used to indicate rates of changes in agricultural practice and the nature of changes in land use. For instance, they are especially valuable in a retrospective study for mapping and analysing the variations of land use both in space and time.

A lot of work has demonstrated the basic reliability and the wide application of the returns. Some examples are mentioned here. In 1962, Best and Coppock revealed **The Changing Use of Land in Britain** through a number of studies in land use statistics and in the mapping and measurement of changes in land use. Later, **An Agricultural Atlas of England and Wales** and **An Agricultural Atlas of Scotland** offered a comprehensive display of aspects of farming and provided a view of agricultural features, based largely upon the district summaries of the annual agricultural returns (Coppock, 1964 and 1976). Then Dawson (1980) gave an example of using the census data to demonstrate "The Great Increase in Barley Growing in Scotland." Also, Robinson (1981) applied multivariate analyses to the parish summaries in "a statistical analysis of agriculture in the Vale of Evesham during the 'great agricultural depression' from 1870 to 1914." The county summaries were further offered as representatives of significant changes in British agriculture (Robinson, 1988). More recently, the work by Wathern *et al* (1988) involved the use of the parish summaries to determine rates of change in agricultural practice in the uplands of North Wales. The statistics in that study were taken as "inaccurate in detail, but reliable in general trend". Furthermore, the parish summaries were used to examine land loss in a small area on the urban fringe of Birmingham and was shown to be best used for indicating land loss in conjunction with aerial photographs (Ilbery and Evans, 1989).

(3) Limitations of the data

Whilst providing a valuable supply of information for land use studies, the statistical data have their limitations. As Robinson (1988) argues, these can be considered from the following aspects: nature of collection, their consolidation into summaries, their accuracy, and their comparability.

The nature of the collection of the agricultural returns is determined by its purpose for obtaining estimates of agricultural production (Best and Coppock, 1962). Unavoidably this underlying purpose leads to some difficulty for land use studies. For example, the actual location of the land to which the summaries refer has little importance to the Ministry of Agriculture (Coppock, 1988), whereas it is of essential significance for the monitoring of changes in land use. The unsatisfactory working of the collection also results from obstacles such as the lack of complete coverage of the total agricultural area, opposition from farmers and the alteration of the basis of collection with regard to the minimum size of holding. In Britain, there is no cadastral survey. Therefore, land can be omitted from the returns. Small holdings are often missed in the returns and common land is excluded. All these can contribute to the incomplete coverage of agricultural land. Also, there could be problems associated with farmers' interpretation of the questions sent to them.

Consolidation of the returns from individual farms into parish summaries often results in discordances between the agricultural boundaries and the boundaries of civil parishes. There is no fixed relationship between parish and farm boundaries as farm boundaries can often straddle parishes. Some farmers may own many farms which are situated in different parishes but data may be returned under only one parish. Therefore the "agricultural" boundaries between parishes, *i.e.*, the boundaries of holdings that comprise the agricultural parish summaries, may well differ from those of civil parishes (Coppock, 1976b). This discrepancy between the parish and the land to which the summaries refer is likely to have increased as holdings have grown larger, but in no systematic way (Coppock, 1988). In addition, parishes with few holdings must sometimes be amalgamated with others (for purposes of confidentiality), although such amalgamations do not necessarily take place between adjacent parishes and may even be between parishes at opposite ends of a county (Coppock, 1988). In consequence, it is virtually impossible to determine precisely the location of different land uses within a parish. The non-availability of data for individual farms only exacerbates the problem.

Finally, limitations also arise from the complexity of the data, *e.g.*, the area of agricultural land recorded in a parish changes with time. "No single item is strictly comparable throughout the period for which the (agricultural) returns have been collected" (Best and Coppock, 1962). Apart from land returned in the wrong parish, changes in categories have occurred over time, *e.g.*, the definitions of both temporary and permanent grassland have been altered frequently. "The information requested on the questionnaires sent to farmers has varied considerably over the years as successively more and more information is demanded of them to suit the changing pattern of farming in the nation and also to eradicate ambiguities and errors which have come to light over the hundred or more years that the returns have been made. This naturally leads to difficulties when studying the changing agricultural pattern of an area" (Tarrant, 1974:P71). Also, there has been reorganisation of county and parish boundaries, *e.g.*, during 1974 (Wathern *et al*, 1988).

The significance of this situation is that it has made it difficult to formulate detailed comparisons and generalisations of regional land use which are simple and true. There has been recent change in the measurement of the size of the total holding as well. It now includes the land under such features as buildings and roads, not simply the total acreage of crops and grass and rough grazing.

For a land use study, the major problem in using the parish summaries arises from the lack of suitability of the parish as the basic unit (Robinson, 1981), which usually precludes a detailed and precise study of land use patterns and changes in the spatial distribution. However, provided that the specific shortcomings of the data are recognised and caution is given in using the data, the parish summaries form an invaluable body of data which can offer a guide to regional variation in British agriculture since 1866. Moreover, the errors in the summaries have decreased since their inception and the wealth of data and their detail should not be ignored. For instance, the agricultural returns were collected on a voluntary basis before 1917. Defects in the returns were supplied by estimation. But returns later became compulsory and proprietors were given assurances of confidentiality. Despite all the limitations, the agricultural returns "remain a source of information about current and past agricultural practices without which rural studies would be the poorer" (Clark, 1982).

(4) Data used in this research

Parish summaries of agricultural statistics for sixty-one parishes within the case study area in South-East Scotland were obtained for the years 1947, 1950, 1955, 1960, 1965, 1969-1972, 1976, 1979-1981, and 1984-1987. These data were analysed to show changes in land use in the Lammermuir Hills. The starting year of 1947 marks the beginning of a major post-war commitment to agriculture by the British government and is therefore a significant date in British agricultural history. Data before 1969 were obtained from the Scottish Record Office in Edinburgh, using a five-yearly interval. This gives a guide to major agricultural changes occurring following the 1947 Agricultural Act and prior to major changes in policy in the late-1960s anticipating entry to the EEC. The summaries are available on computer tape from the University of Edinburgh Data Library, for the periods indicated after 1969.

The items extracted from the summaries include: land under crops and fallow; acreages of winter wheat, barley, oats, ware potatoes, turnips and swedes, and oilseed rape; land under farm woodlands and rough grazing; and number of sheep and cattle. They were selected as the principal indicators of agricultural change. Because of their limitations, parish summaries are essentially a subsidiary or additional source of information which can be combined with remotely sensed imagery to enable a more detailed investigation of land use/land cover change in terms of object classes or at a micro-scale.

3.2.2 Landsat imagery

(1) Availability and acquisition

Remote sensors are data-gathering devices which operate without being in direct contact with the object about which they are collecting information. Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by remote sensors. Data gathered by the Landsat family satellites which have been in orbit around the Earth since the early 1970s are an important source of remotely sensed data for this study.

The first Landsat was launched on 23 July 1972, as an experimental system to test the feasibility of collecting earth resource data from unmanned satellites. The results of world wide experimentation with the system were overwhelmingly favourable. Since then, NASA Landsat series of satellites have provided remotely sensed digital image data for all parts of the world, excluding areas above 80^0N and below 80^0S. To date, there are five satellites in the Landsat series and they fall into two groups: Landsat -1, -2, and -3 are the first generation Landsats with two sensors of Return Beam Vidcon (RBV) and Multi-spectral Scanner (MSS) while Landsat -4 and -5 are the second generation Landsats carrying a standard MSS and an improved MSS called the Thematic Mapper (TM). Figure 3.4 shows a detailed Landsat time line.

The MSS systems utilise electronic energy and cover a 185 kilometres' swath width in four spectral wave bands simultaneously. They are band 4 and band 5 in the visible

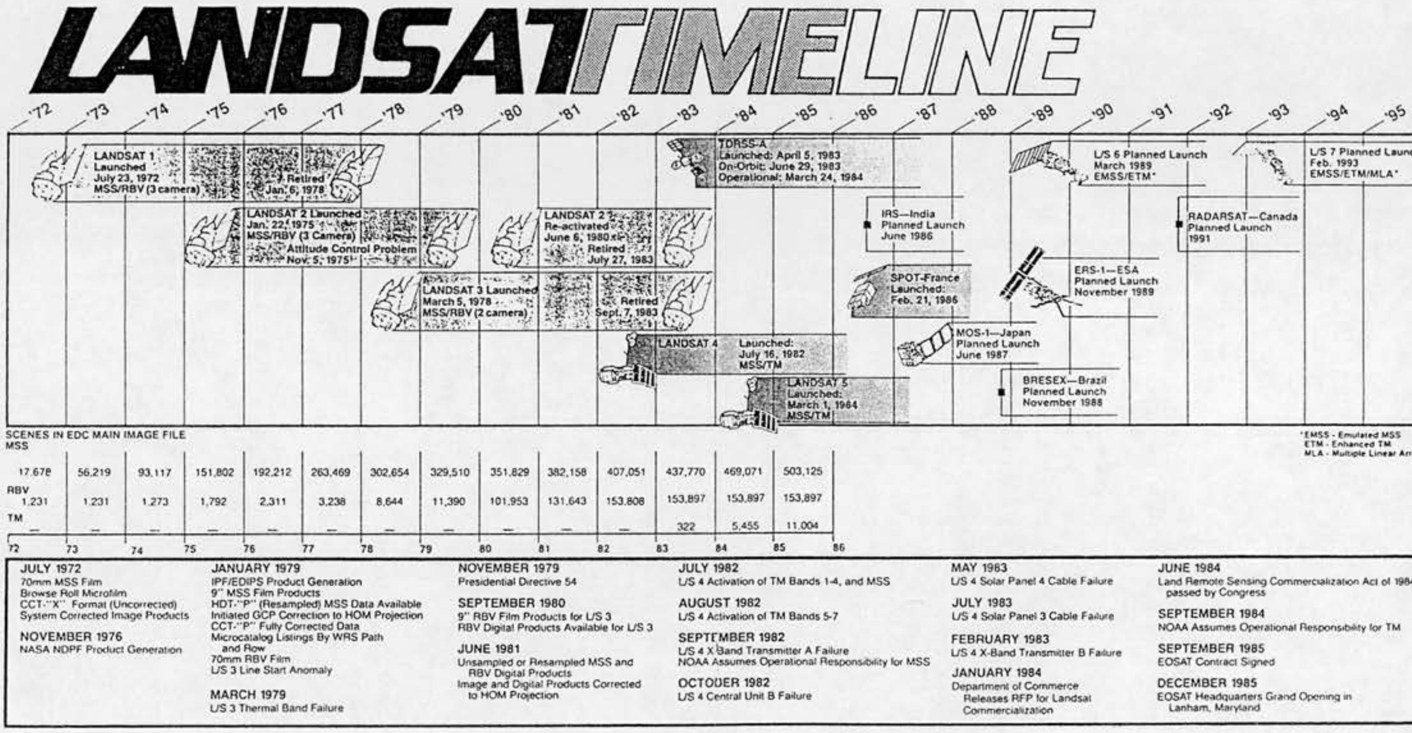

Figure 3.4 Landsat time line (After EOSAT 1986)

spectrum at 0.5-0.6 *m* (*Green*) and 0.6-0.7 *m* (*red*); and band 6 and band 7 in the reflected infrared at 0.7-0.8 *m* and 0.8-1.1 *m* respectively. The satellites weigh about 815 kg and were launched into circular orbits at a nominal altitude of 900 km. It takes 18 days for the Landsat orbit pattern to progress westward to the point of coverage repetition. Thus each Landsat satellite passes over the same area on the earth's surface during daylight hours every 18 days. But the actual number of times per year a given ground area is imaged depends on amount of cloud cover, sun angle, and whether or not the satellite is in operation on any specific pass. Because of the overlap between orbits, the potential frequency of repetitive coverage at the latitude of Southern Scotland is more frequent than 18 days.

The MSS operating configuration is shown in Figure 3.5. The instantaneous field of view (IFOV) of the scanner is square and results in a ground resolution cell of approximately 79 m on a side. A pixel is the cell of its digital image set and contains a set of digital numbers for each spectral band. The analog signal from each detector is converted to digital form by an onboard A to D converter. The dynamic range of the digital values is 0 to 127 for bands 4-6 and band 7 is scaled to 0 to 63. The A to D converter samples the output of the detectives about 100 000 times a second, resulting in a nominal ground spacing of 56 m between readings (Lillesand and Kiefer, 1987). Because of this spacing, the image values form a matrix of 56 m x 79 m cells, although the

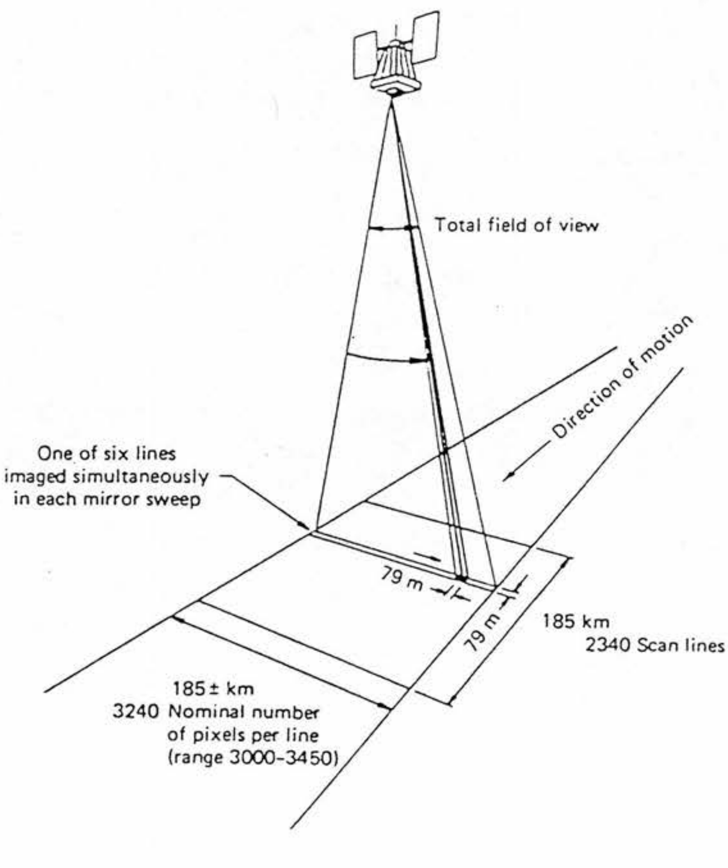

Figure 3.5 Landsat MSS operating configuration

(Adapted from Lillesand and Kiefer, 1987:P543) brightness value for each pixel is actually derived from the full 79 m x 79 m ground resolution cell. A 56 m x 79 m "nominal" pixel dimension is also often referred to instead of the actual 79 m x 79 m ground area over which each MSS measurement is made. This therefore results in an overlap of the areas from which measurements are made for adjacent pixels. When a Landsat satellite is within line-of-sight of a receiving station, MSS data are directly transmitted in real time and recorded on magnetic tape at the ground station. The MSS data are digitised by an onboard A to D converter and transmitted in a digital format back to the ground, processed and then stored on computer compatible tapes as 8-bit digital numbers ranging from 0 to 255. As a line scanning system, the Landsat MSS produces images having one-dimensional relief displacement. Because of the high altitude and narrow field of view of the MSS, images from the scanner contain little to no relief displacement in areas of moderate relief.

Several technical improvements have been made in the manner in which Landsat data are processed prior to distribution. Hence, the precise form of Landsat-1, -2, and -3 data products has varied considerably over the course of time. For example, digital MSS data supplied in computer compatible tape (CCT) format after 1979 were resampled into pixels having a nominal dimension of 57 m x 57 m (compared with the 56 m x 79 m size used previously).

Landsat-4 and -5 were launched into orbits with a lowered altitude of 705 km to make the satellites potentially retrievable by the Space Shuttle and to aid in the improvement of the ground resolution of the sensors onboard. The orbits also results in a 16 day repeat cycle for each satellite. Figure 3.6 shows the design of the Landsat-4 and -5 satellites which include both the MSS and the TM. The spacecrafts weigh approximately 2000 kg. The MSS onboard Landsat-4 and -5 is essentially identical to the MSS sensors on the previous Landsat satellites. The across-track swath of 185 km has been maintained and the same four spectral bands are used for data collection.

The TM is a highly advanced multi-spectral scanner incorporating a number of spectral, radiometric, and geometric design improvements relative to the MSS. The TM systems acquire data in seven spectral bands instead of four, with new bands in the visible, mid-infrared, and thermal portions of the spectrum. The wavelength range and location of the TM bands have also been chosen to improve the spectral differentiability of major earth surface features (see Table 3.1). Geometrically, TM data are collected using a 30 m x 30 m ground resolution cell. As shown in Table 3.1, the TM bands are designed more finely for vegetation discrimination than those of the MSS. The near-infrared TM band (4) is narrower than the combined bands of the MSS in this region and centred in a region of maximum sensitivity to plant vigour whilst sensitivity to plant water stress is obtained in both of the TM mid-infrared spectral bands (5 and 7).

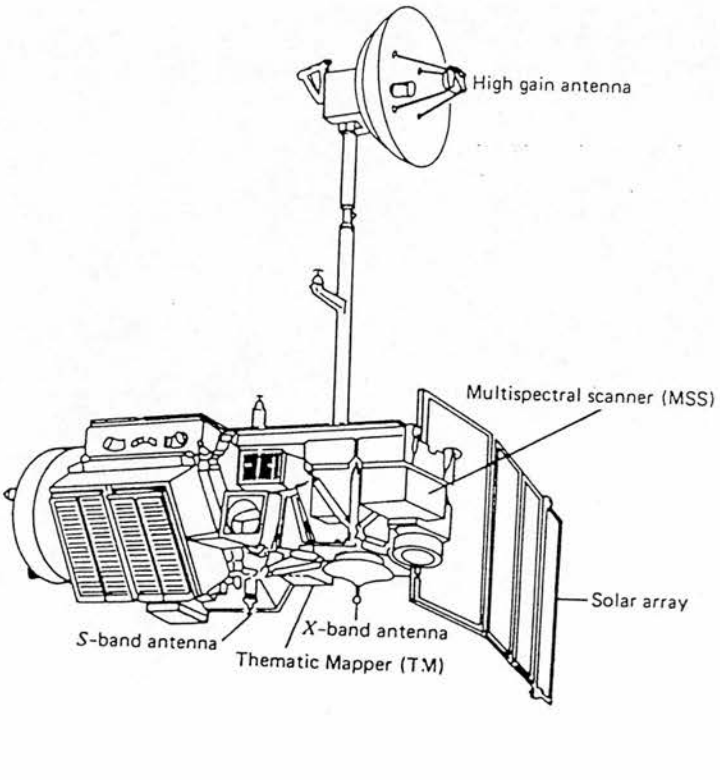

Figure 3.6 Landsat -4 and -5 observatory configuration
(Adapted from Lillesand and Kiefer, 1987:P565)

Table 3.1 Thematic Mapper Spectral Bands (Adapted from Lillesand and Kiefer 1987)

Band	Wavelength (μm)	Nominal spectral location	Principal applications
1	0.45–0.52	Blue	Designed for water body penetration, making it useful for coastal water mapping. Also useful for soil/vegetation discrimination, forest type mapping, and cultural feature identification.
2	0.52–0.60	Green	Designed to measure green reflectance peak of vegetation (Figure 1.10) for vegetation discrimination and vigor assessment. Also useful for cultural feature identification.
3	0.63–0.69	Red	Designed to sense in a chlorophyll absorption region (Figure 1.10) aiding in plant species differentiation. Also useful for cultural feature identification.
4	0.76–0.90	Near-infrared	Useful for determining vegetation types, vigor, and biomass content, for delineating water bodies, and for soil moisture discrimination.
5	1.55–1.75	Mid-infrared	Indicative of vegetation moisture content and soil moisture. Also useful for differentiation of snow from clouds.
6[a]	10.4–12.5	Thermal infrared	Useful in vegetation stress analysis, soil moisture discrimination, and thermal mapping applications.
7[a]	2.08–2.35	Mid-infrared	Useful for discrimination of mineral and rock types. Also sensitive to vegetation moisture content.

[a]Bands 6 and 7 are out of wavelength sequence because band 7 was added to the TM late in the original system design process.

(2) Interpretation and application

Numerous studies have been undertaken to demonstrate the utility of the Landsat data for a wide variety of earth resource applications, especially for surface cover mapping. Landsat data have been used a great deal as a planimetric mapping tool in certain areas of the world. The most appropriate band or combination of bands of Landsat imagery are usually selected for each interpretive use. For instance, a normal colour composite of TM bands 1, 2, and 3 was preferred for the mapping of water sediment patterns (Lillesand and

Kiefer, 1987:P573). Some other examples concerning the application of Landsat data are as follows. Bauer *et al* (1979) reported an 80 per cent accuracy on identification and area estimation of agricultural crops in northern Illinois by computer classification of Landsat MSS data. A survey based on Landsat data also showed the distribution and area of winter oilseed rape within eastern Scotland (Wright, 1985). Furthermore, Birnie (1988) summarised how relevant information could be extracted and used in the context of regional planning with examples in mapping potato crop distribution and afforestation prediction. Examples of remote sensing application for local resource planning were also given by Harding (1988), *e.g.*, monitoring change at the urban-rural boundary and woodland mapping with Landsat TM data.

Because of differences in scale and resolution between Landsat images and conventional aerial photographs, Landsat images are sometimes considered as a complementary interpretive tool for low altitude aerial photographs (Lillesand and Kiefer, 1987:P546). A photograph 'scale' is an expression that states that one unit of distance on a photograph represents a specific number of units of actual ground distance, while the 'spatial resolution' of a sensor is an indication of how well a sensor can record spatial details and the ground segment sensed at any instant is called the ground resolution element or resolution cell. The effective spatial resolution of Landsat MSS images is about 79 metres. But linear features as narrow as a few metres, having a reflectance that contrasts sharply with that of their surroundings, can often be picked out on Landsat images. MSS bands -4 (green) and -5 (red) are usually best for detecting cultural features such as urban areas, roads, gravel pits and quarries. Bands -6 and -7 (near infrared) are best for delineating water bodies. Surface water features have a very dark tone in these two bands because the energy of near-infrared wavelengths penetrates only a short distance into water, where it is absorbed with very little reflection.

Landsat TM images are useful for image interpretation for a much wider range of applications than Landsat MSS images because the TM sensor has both an increase in the number of spectral bands and an improvement in spatial resolution as compared with the MSS. The MSS images are most useful for large area analyses, such as geological mapping. More specific mapping, such as detailed land cover mapping, is difficult because

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of the existence of a large number of "mixed pixels", which are pixels containing more than one type of land cover. One example of examining effects of mixed pixels is the work done by Birnie (1986) for identifying snow condition from Landsat MSS data. The TM imagery, with decreased IFOV and improved spectral and radiometric resolution, contains fewer mixed pixels and thus leads to increased accuracies of image interpretation (Lillesand and Kiefer, 1987:P570). TM data have been used extensively to prepare image maps over a range of mapping scales, which have proven to be useful tools for resource assessment in that they depict the terrain in actual details rather than in the line-and-symbol format of conventional maps.

While a wealth of information can be extracted manually from Landsat data in a hard copy format, the overwhelming volume of these data and their inherent digital form make them much more amenable to computer-assisted analysis. A multitude of procedures has evolved to deal with Landsat data in their computer compatible tape (CCT) format which provides the most faithful rendering of each scene as sensed electronically and recorded digitally.

The basic procedure for analysing Landsat data includes image correction, image enhancement and image classification. Prior to the actual interpretation, correction techniques applied to Landsat data act to minimise problems of image distortions and to restore and to generate image data which are more useful, while image enhancement techniques can be employed to accentuate the contrast between features in the scene and thus to increase the amount of information extracted from the image data. The aim of image classification procedures is to automatically interpret digital image data and categorise all pixels in an image into land cover classes or themes. Each pixel observation is evaluated and assigned to an information category, thus replacing the image data with a matrix of category types.

Whilst satellite remote sensing generates a wide variety of data, especially advantageous in providing data collection over a large area in terms of cost efficiency, its increasing compatibility with computer-based systems such as GIS particularly enhances its value. Rapid advances in computer technology in terms of interactive capability and lowered computational costs have increased users' ability to interact with GIS processes.

Remote sensing can update GIS data planes while GIS can provide for the efficient use of the ancillary data required by remote sensing (Estes, 1984).

(3) Images used in this research

With its well-asserted appropriateness and reliability, applications of satellite imagery in land use/land cover studies have increasingly become acceptable and essential. Moreover, there is an urgency for further exploiting the technologies and techniques associated with remote sensing under the growing pressures on the environment. As mentioned in Chapter 1, the classification and mapping of land use/land cover via the use of Landsat imagery form the major focus of this thesis. Two images, which were the only readily available images covering the study area in the Department of Geography, were used for this research. One was the MSS image for 24 April 1984 with 79 m x 56 m ground resolution and the other was the TM data for 14 September 1986 with 30 m x 30 m ground resolution. In general, these images are of good quality and are largely cloud free over the major part of the study area.

3.2.3 Other data involved in the research

Improvement in digital classification of Landsat data can be achieved through the incorporation of ancillary data, which are usually map-based, such as the Ordnance Survey topographic maps, soil maps and maps of land capability for agriculture. They are digitised manually into ARC/INFO and stored in vector format and then either transferred to raster data to assist imagery analysis on the GEMSTONE image processing system or for further analysis by overlaying different data contents in ARC/INFO.

The interpretation of aerial photography can be combined with ground survey data to provide selected land use/land cover information. This has been proven as a well-established methodology (Coppock and Kirby, 1987). Aerial photographs can provide low and medium altitude data for multi-level land use/land cover classification. Meanwhile it is an important data source for selection of certain training and testing fields in analysis of Landsat data (*e.g.* Hubbard, 1985). However, aerial photographs have not been used as a major data source in this study because one of the objectives of this research is to test the feasibility of high altitude digital satellite remote sensing data in land use studies over a large area, and there was no available facility then in the Department of Geography to ensure interpretation of aerial photographs to be geometrically correct and to transfer interpreted results into digital form. Also the only available photographs covering the required area in the Department of Geography at the time of the study were these for the year 1981.

Other data, such as the Farm Cropping Programme by the Edinburgh Centre of Rural Economy, offer a uniquely detailed set of ground truth information. Specifically, in this study, Bush Estate is a small area south of Edinburgh with considerable diversity of terrain and land cover types while having a natural ecological system and a farming system similar to that of the Lammermuir Hills area. The cropping plan records the crops grown in each field, which are harvested in the stated year. The data can be cartographically represented by matching field names and crops grown in the field. The resultant map can then be used as ground truth data for defining training areas prior to image classifications, taking into account data for both image and farm records.

3.3 Monitoring Changes in Land Use

For this study, a combination of data sources was used to monitor changes in land use. Initially, by a detailed statistical analysis of parish summaries, a general picture of changing agricultural land use can be obtained. This throws some light on the pattern of regional land use and indicates the trends and rates of changes in land use during the past forty years. It also provides a guide to regional land use and is of importance for the start of other approaches, *e.g.*, the analysis of Landsat images in this case. It enriches the analyst's background knowledge to the study area. The feasibility of monitoring changes in land use/land cover via the use of Landsat images and other ancillary data was then explored and tested, as part of an evaluation of the effectiveness of Landsat imagery data for an integrated study of changes in land use/land cover.

3.3.1 Analysis of agricultural returns

Changes in land use in South-East Scotland since the 1940s were demonstrated by mapping the agricultural statistics at parish level, monitoring temporal changes in the study area and applying a correlation analysis of land use variables.

(1) <u>Cartographic representation of agricultural returns</u>

If the full significance of agricultural statistics for land use study is to be appreciated, they need to be represented cartographically (Best and Coppock, 1962). Fortunately, there has been a marked development in the use of computers in geographical research and they have been used to produce numerous maps, illustrating a wide spectrum of agricultural activity (Hotson, 1976). Rapid progress in computer development has made it possible for geographers to manipulate the output of computation to provide a spatial answer to a calculation. Among a number of output devices for computer mapping, line printers have advantages in providing an efficient means of mapping spatial data in a similar way to a typewriter. For instance, the CAMAPGB1 program, available from the University of Edinburgh, is a package with a built-in map framework of Great Britain at parish level. It operates on a fixed grid, mapping spatial data from left to right, grid-cell by grid-cell and line by line down the map. It can indicate data values by grid squares, with a set of characters specially designed for drawing maps. The principle behind the program is that a large set of areally important values have to be grouped and the groups are indicated on the map by symbols instead of numbers. All the maps can be modified by changes in calculations presented and in the intervals chosen for shading. Shading is accomplished by choosing suitable symbols to indicate increasing or decreasing values and printing these symbols in the appropriate grid squares of the line-printer map. Due to the fact that the areal extent of parishes varies greatly, and also the total acreages of agricultural land per parish change with time, the most satisfactory solution to show the areal variations of crops and to make comparisons over time is to consider changes, not in absolute values, but in proportions of land under particular crops or densities and ratios of livestock (Hotson, 1976). Careful choice of the scaling factor and class intervals can then be used to emphasise different aspects of the data.

Using CAMAPGB1, the following results were mapped for each parish in the study area for the years selected.

Proportion of total agricultural land under crops and fallow

Proportion of total arable land under winter wheat

Proportion of total arable land under barley

Proportion of total arable land under oats

Proportion of total arable land under ware potatoes

Proportion of total arable land under turnips and swedes

Proportion of total arable land under oilseed rape

Proportion of total agricultural land under farm woodlands

Proportion of total agricultural land under rough grazing

Number of cattle for every 100 ha of total agricultural land

Number of sheep for every 100 ha of total agricultural land

These selected items are considered by the analyst as principal indicators of agriculture and agricultural change in the study area, especially in relation to changes in land use. The results of the map series from CAMAPGB1 are presented in Appendix 2. By visually and statistically analysing and interpreting the map series for individual variables, characteristics of the spatial distributions for each variable can be revealed as well as the integrated pattern of land use in the area. Maps showing proportions of land in tillage under winter wheat, barley, oats, potatoes, oilseed rape, and turnips and swedes were used to examine various alterations within arable production.

(2) Temporal changes

Apart from mapping the study area by parishes to show the spatial pattern of land use and trends of change, data for each variable plotted against time demonstrated the trends of change for each variable over the same time period, and therefore established possible inter-relationships between different variables.

The balance between arable and grass on the cultivated area is an important yardstick for agricultural production (Holderness, 1985). Therefore the temporal changes in the acreages of arable land and grassland for the study area were presented and compared. Further trends of changes within arable land were examined by studying individual crops. Changes in total farm woodland and rough grazing were also analysed.

Results of the analysis on temporal changes of different variables are presented in Section 4.3 of Chapter 4.

(3) Correlation analysis

Although the concomitant change for different variables can help to identify visually the possible inter-relationships between them, a correlation analysis of these variables was preferred to examine the inter-relationships quantitatively and more clearly. Both a temporal analysis and a spatial analysis were employed in this study.

First, a correlation analysis was carried out between each pair of variables in terms of changes through time. The mean values for the sixty-one parishes over the seventeen years were used, regarding the proportions of arable land, rough grazing, farm woodland and grassland respectively. In addition to analysing how the variables were related over time, they were also correlated for each of the selected seventeen years. The correlation coefficients for each year were obtained using the data for the sixty-one parishes within the same year, regarding the proportions of arable land, rough grazing, farm woodland, grassland and densities of cattle and sheep. A complete set of inter-relationships was established between different variables. The trend and rates of changes in land use can thus be analysed. Details on the correlation analysis can be referred to in Chapter 4 and Appendix 3.

(4) Summary of the statistical analysis

On the basis of the aforementioned individual analysis, the integration of the mapping and the correlation analysis of agricultural statistics revealed the general characteristics of the land use pattern. Certain trends of changes in land use could also be identified from the maps and correlation analysis. Finally, the inter-relationships between variables were summarised and discussed. The results are shown in Chapter 4.

3.3.2 Analysis of Landsat images

The major objective of the study was to test the feasibility of monitoring changes in land use/land cover through the use of Landsat imagery. The initial requirement was for a land use survey. To fulfil this task, several steps were necessary.

(1) Geometric correction

As a first step, the Landsat imagery was geometrically corrected and resampled. This helped to eliminate spatial distortions of the image, stemming from many factors which affect the collection of remotely sensed data. For instance, minor variations in the altitude or velocity of spacecraft are well known to cause either over-sampling or under-sampling of pixels which results in the image being either elongated or shrunk along one axis. The need for geometric correction also arose because the natural coordinate system of most images is often inconvenient for many scientific purposes, *e.g.*, studying images from different sources with different spatial resolutions or at different dates, or studying remotely sensed data in conjunction with existing maps.

The procedures employed in geometric correction generally treat the distortions as belonging to two groups: systematic or predictable distortions versus those considered to be essentially random or unpredictable.

Systematic distortions can be well understood and easily corrected by applying formulae derived by mathematically modelling the sources of the distortions. This would involve attempting to define all of the remote sensing platform characteristics relevant to determining the geometric properties of the final image, such as satellite orbital track, orbital height and rate of forward movement. A transformation can then be derived and, in return, used to convert the image data to the required metric. For example, a highly systematic source of distortion involved in multispectral scanning from satellite altitudes is the eastward rotation of the earth beneath the satellite during imaging. This causes each optical sweep of the scanner to cover an area slightly to the west of the previous sweep. This *skew distortion* can be corrected by offsetting each successive scan line slightly to the west. The images used for this study did not show problems with systematic distortions and therefore the process of correction has been saved.

Random distortions and complex systematic distortions were corrected by analysing ground control points, assuming that there was some arbitrary relationship between the geometry of the imaged scene and the geometry of the scene required for analysis. This requires the availability of accurate maps of the image area and image identifiable ground control points. The relationship can then be identified by examining the relative locations of a set of ground control points on the image coordinate system, and is used to relocate the pixels of the input image to those in the output image. The values of these ground control points were submitted to a least squares regression analysis to determine coefficients for two transformation equations that interrelate the geographic and image coordinates x and y:

$x = f_1(X,Y)$

$y = f_2(X,Y)$

where (x,y) = Image Coordinates

(X,Y) = Map Coordinates

f_1 f_2 = Transformation relationships

Once the acceptable transformation was obtained, the image data were transformed to the required ground coordinate system. This involved selecting a suitable set of dimensions for the output data-set, using the inverse of the transformation matrix to locate each output pixel in the image data and computing a value to represent the output pixel from the input image. This process is called **resampling**. If the output pixel value is always replaced with the value of the closest pixel to its location in the input image, the approach is called **nearest neighbour resampling**. This interpolation method offers the advantage of computational simplicity and avoids altering the pixel values. Where significant scale changes are taking place or where a rather smooth output image is required, more sophisticated methods of resampling are often desirable. In that case, once the location of each output pixel in the input image has been found, the output pixel is given a value derived from the nearest 'n' surrounding pixels. Therefore, as alternative methods, the **bilinear interpolation** technique takes a proximity-weighted average of the four nearest pixels while the **cubic convolution** method evaluates a sixteen pixel neighbourhood around each output cell.

The product of the correction procedures was an output image on the same metric as a map of the area which had been imaged and could subsequently be used for overlaying cartographic data onto imagery.

In this study, two images have been corrected for an area measuring approximately 2500 sq. km, delimited by the British National Grid Coordinates:

	Eastings	Northings
Top Left	315000	686000
Top Right	380000	686000
Bottom Left	315000	648000
Bottom Right	380000	648000

The whole process can be subdivided into four parts, using the GEMSTONE Geometric Correction Module.

Initially, selection was made of ground control points (GCPs). A series of recognisable points were selected from the image, displayed on the workstation, using the cursor, and identified on the 1:50 000 Ordnance Survey map of the corresponding area. The scale of 1:50 000 proved to give sufficient information for selection of major features as explained below. The choice of GCPs controlled the success of the overall geometric correction. For the TM image, eleven points were finally used for the transformation and thirteen were used for the MSS image correction. In both cases, the GCPs chosen were easily identifiable and relatively permanent image features, such as road junctions and reservoirs. Another important point is that they were well spread over the study area to avoid any bias in establishing the relationship.

Then comes the calculation of the transformation using the ground control points. For both images, six coefficients were used to fit the x, y pairs with a second order polynomial to achieve correction accuracy.

Once a satisfactory transformation had been achieved, the transformation matrix was saved before proceeding to the next step. The output configuration and the interpolation method were then defined. In order to study the two images with different spatial resolutions, both pixel sizes were resampled to 50 m x 50 m. Then the final area to be corrected was obtained by specifying the top left and bottom right corner coordinates of the output image as the British National Grid coordinates. To get the best quality visual output, the **cubic convolution** method was chosen for the interpolation of the output pixel intensity.

Finally, the geometric correction was carried out using the names and parameters supplied in the last program. A similar procedure was repeated for each spectral band. The corrected image bands in this study were: MSS bands -4, -5, -7 and TM bands -3, -4, and -5. The choice of the Landsat images and the spectral bands used in the study were limited by the availability in the Department of Geography at the time of study. However, previous work has shown that TM bands 3, 4 and 5 are often used and have proved as a good combination for rural land use/land cover classifications.

(2) Training stage

Prior to the actual classification of multi-spectral image data, the training stage is essential to assemble a set of statistics that describe the spectral response pattern for each land cover type to be classified in an image. The quality of the training process determines the success of the classification stage and, therefore, the value of the information generated from the entire classification effort (Lillesand and Kiefer, 1987).

To yield acceptable classification results, training data must be both representative and complete. The training effort in a supervised classification requires a close interaction between the image analyst and the image data. It also requires substantial reference data and a thorough knowledge of the geometric area to which the data apply.

The training sample data are usually obtained by outlining areas using a *reference cursor*. The training set polygons should be carefully located to avoid pixels along the edges between different land cover types. The row and column coordinates of the vertices for these polygons can then be used as the basis for extracting the digital numbers for the pixels located within each training area boundary. These pixel values formed the sample used to develop the statistical description of each training area. In general, the more 'pure' pixels that can be used in training, the better the statistical representation of each spectral class. On the other hand, dispersion of the training sites throughout the scene increases the chance that the training data will be representative of all the variations in the cover types present in a scene.

Often, more than one spectral class is required to adequately train on certain features and all spectral classes constituting each information class must be represented in the training set statistics for classifying an image (Lillesand and Kiefer, 1987). Meanwhile redundant spectral classes in a classification process are not desirable to be included from a computational standpoint. Such gaps and redundancies can be identified during the process of training set refinement, in which the analyst revises the statistical descriptions of the category types until they are sufficiently spectrally separable. That is, the original set of 'candidate' training area statistics is revised through merger, deletion and addition to form the 'final' set of statistics used in classification. Training set refinement is usually the key to improving the accuracy of a classification. Alternative methods, perhaps including visual interpretation or field checking, can be used to discriminate these cover types. Multi-temporal or spatial recognition procedures may also be applicable.

In this study, the ground truth data for training the classifier have been extracted from a combination of aerial photo interpretation, analysis of cropping plan record data, and data from maps.

Interpretation of aerial photographs for the required study area was helpful in identifying woodlands, water surfaces, cultivated land and built-up areas. However, there were difficulties in discriminating between fields with different crops. Also for this study, there were not available aerial photographs taken during the same year and the same seasons as the Landsat images used. The only available aerial photographs for the area in the Department of Geography were taken during 1981.

The record data of the Farms Division Cropping Plan in Bush House's Farms Cropping Programme helped to solve this problem to a large extent. The record data provided a detailed set of ground truth information. As mentioned in Section 3.2.3, the record data can be cartographically represented by matching field names and the crops grown in the field. Thus the aspatial data of agricultural statistics were mapped into spatial form. The resultant maps were then used to define training areas, taking into account data for both the image and the farm record. The statistics generated from the training sample data in Bush Estate area can be applied to the Lammermuir Hills area for the execution of image classification because both areas have similar farming and land use systems and also appear on the same scene of Landsat images. The farm record data used were also taken in the same year as the Landsat images. These data have been most useful in defining fields with different crops and grassland. But their geographic bias requires supplement of other data or interpolation of the same features over other areas.

The updated Ordnance Survey topographic maps assisted to identify features of woodlands, urban areas, moorlands and reservoirs on the Landsat images. Other map-based data such as maps showing road systems and river networks, soil maps and a map of land capability for agriculture were digitised into ARC/INFO and then transformed from vector to raster format for input to the image processing system to assist the image analysis. They helped with the visual identification of certain features on the images and improve the interaction between the image analyst and the image data by providing a better knowledge of the study area.

Apart from using the available training data, visual interpolation was found useful in selecting the training areas, based upon both the knowledge from the spectral characteristics of different ground covers and that obtained from the analysis of known ground covers. For example, some known crop fields in the Bush Estate area helped the analyst to interpolate areas in the Lammermuir Hills with identical spectral signatures and textures. Strictly speaking, visual interpolation is subject to the analyst's subjective decision. But to a certain extent, this supplemented the insufficient number of pixels and their dispersion, resulting from the lack of known areas. Details on how visual interpolation or deduction has been used can be found in Chapter 5.

The training set refinement process is an iterative procedure. In this study, the number of the spectral classes has been increased in order to represent each information class, and thus more pixels in the image could be classified. Also it was a key to improving the accuracy of the classification.

(3) Integrated classification

The aim of image classifications is to automatically categorise all pixels in an image into land cover classes or themes. This normally involves the analysis of multispectral image data and the application of statistically based decision rules for determining the land cover identity of each pixel in an image. Using the numerical descriptions of the spectral attributes of each training category as interpretation keys, pixels of unidentified cover type are categorised into their appropriate classes. This type of classification involving the comparison between unknown pixels and training set pixels is described as *supervised classification*. Numerous mathematical approaches to spectral pattern recognition have been developed, and there are different strategies in carrying out a classification. The most popular supervised classification strategies in the commonly-used image processing systems are the minimum distance classifier, the parallelepiped classifier and the maximum likelihood classifier (Lillesand and Kiefer, 1987).

The **Minimum-Distance-to-Means** classifier is one of the simple and computationally efficient strategies. The mean spectral value in each band for each category comprises the *mean vector* for each category. By considering the pixel values as positional coordinates, a pixel of unknown identity may be classified by computing the *distance* between the value of the unknown pixel and each of the category means. The unknown pixel is then assigned to the "closest" class. If the pixel is farther than an analyst-defined distance from any category mean, it would be classified as "unknown." The major limitation of this strategy is its insensitivity to different degrees of variance in the spectral response data. Therefore this classifier is not widely used in applications where spectral classes are close to one another in the measurement space and have high variance.

The **Parallelepiped Classifier** evaluates an unknown pixel according to the category range, or *decision region*, which may be defined by the highest and lowest digital number values in each band. The pixel is classified as "unknown" if it lies outside all regions. With increased sensitivity to category variance, difficulties are encountered when category ranges overlap, which is caused largely because category distributions exhibiting correlation or high covariance are poorly described by the decision regions. Unfortunately, spectral response patterns are frequently highly correlated and high covariance is often the rule rather than the exception.

The **maximum likelihood classifier** quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel, assuming the distribution of the pixels forming the category training data is normally distributed. This assumption of normality is generally reasonable for common spectral response distributions. Under this assumption, the distribution of a category response can be completely described by the *mean vector* and the *covariance matrix*. Then the statistical probability of a given pixel value can be computed. After evaluating the probability in each category, the pixel would be assigned to the most likely class, or labelled "unknown" if the probability values are all below a threshold set by the analyst. By taking most variables into combination, the maximum likelihood classifier generally provides more classification accuracy and gives the best results compared with other techniques (Lillesand and Kiefer, 1987). It was supported in the empirical study by Booth and Oldfield (1989) in which the maximum likelihood algorithm provided the most accurate classification in a comparison of four classification schemes--minimum distance, decision tree, maximum likelihood and a modified minimum distance classifier. The chief drawback of this technique is the large number of computations required to classify each pixel. Therefore, the maximum likelihood classifier is much slower computationally, especially when either a large number of spectral channels are involved or a large number of spectral classes must be differentiated.

For this research, the integrated land cover classification, *i.e.*, the classification which took into consideration of the spectral characteristics of all the defined land covers instead of single cover identification, was carried out on a pixel by pixel basis using a maximum likelihood classifier to achieve the best classification accuracy. With the GEMSTONE modules, the statistics generated from the defined areas can be saved as a VMS file. This file was thus available for editing or tailoring and retrieving for further use.

The training set refinement process is the key to improving the classification results. Training and classification are not totally separate processes. They are inter-related and supplementary to each other. To obtain satisfactory classification, trial and error is necessary. By visually evaluating or sampling the classification results, problems can be recognised clearly. Modification of some spectral classes or inclusion of certain new spectral classes are often needed. Then the training set can be refined step by step. Sometimes classification on a masked area with a particular training set of spectral classes is desirable in order to avoid some obvious errors such as pixels classified as built-up areas on the moors or built-up areas classified as moors. The combination of these strategies can usually bring an improvement in the results of image classifications.

For both the TM and the MSS images in this study, based upon the performance of the image classification over the whole study area, difficulties were encountered in discriminating between urban areas and moorland, due to the similarities in their spectral reflectance values. The segmentation of the image into subscenes for classification helped to reduce these obvious errors. For example, pixels classified as built-up areas on the moors can be readily excluded and *vice versa*. Different sets of training statistics were used for different segments. The results of classification on subscenes were then copied into one image with the same pixel size and location as prior to the classification. This newly combined image shows the results of image classification for the whole study area. More details on how the classifications were improved can be referred to in Chapter 5.

The classified data often manifest a salt-and-pepper appearance due to the inherent variability encountered by a classifier on a pixel-by-pixel basis. Spatial filtration modifies the values for each pixel by considering the pixel values that surround it. The majority mode filter smooths an image by replacing each pixel with the mode value of the pixels in the surrounding region delimited by the filter size (The mode value is the value with most occurrences). Therefore, there is no additional classes being created when a mode filter is used on a classified image. Isolated pixels can be removed through the filtration and the smoothed classified output shows only the dominant (presumably correct) classification. After applying the post-classification majority mode filter, the proportion of mixed pixels remaining unclassified was also reduced to a large extent. This reduced variability and mixed pixels is of substantial significance in the following transference to ARC/INFO. It saved the required CPU time and disk space to a large degree by handling a reduced number of polygons.

The classified image file was subsequently recoded into feature classes for rapid combination of classes prior to transference to ARC/INFO or for redisplay on the GEMSTONE workstation. By defining the same set of information classes for images of different dates, it helped to meet the need for the standardisation of the remotely sensed data. Meanwhile the compatibility with conventional classification systems should be considered.

(4) Accuracy assessment

Landsat imagery classification enabled rapid generation of land cover maps, from which land use maps have been derived using other information. But user acceptance has lagged behind due to difficulties in the specification and statistical testing of accuracy (Card, 1982). Any applicable map should be associated with post-classification accuracy assessments because of the existence of errors in all remote sensing work. Usually accuracy assessments include both map accuracy testing and area estimates. The map accuracy evaluation involves statistical sampling of individual areas of known cover types, which offers an effective method of examining inclusive and exclusive classification errors. As for the accuracy of area estimates, this can be assessed by comparison of area estimates from image classification with those obtained by conventional methods. Overall accuracy can be evaluated only by considering areas that are different from, and considerably more extensive than, the training areas. This evaluation is generally performed after the classification and output stages, but ideally it should be a part of the training evaluation. Among the general criteria proposed by Anderson *et al* (1976) for developing the classification system is that the minimum level of interpretation accuracy in identifying land use and land cover categories from remote sensing data should be at least 85 per cent. Therefore land use/land cover classifications may have to be repeated before satisfactory results can be achieved.

In this study, the accuracy assessment was carried out on the defined feature classes only, namely, water surface, grassland, pasture, arable land, moorland, forest land, and built-up area. The random sampling of the individual pixels was applied to each class with a sample size determined by its weight in the whole image and the "preliminary estimate" of accuracy (Hay, 1979; Rosenfield *et al*, 1982). Each sample point was then checked with updated Ordnance Survey 1:25 000 map sheets and supplemented by field checking. *A priori* knowledge also permits a decision to accept or reject the classification of certain pixels. A contingency table can then be produced, showing the following aspects: the frequency that any one land use/land cover type (on the ground) is erroneously attributed to another class; the frequency that the wrong land use/land cover (as observed on the ground) is erroneously included in any one class; the proportion of all sampled pixels which are misclassified; and the determination of whether the errors are random or subject to a persistent bias. Then the classification performance for each class can be assessed as well as the overall classification accuracy based upon the results shown on the table.

(5) Comparisons of classification results

Satisfactory results of image classification for different dates can be compared to show changes in land use/land cover. This can be achieved either by using the GEMSTONE image processing system or by transferring the digital classification results to ARC/INFO after filtering of the images and recoding each class to a new group. Detection of changes in land use/land cover using GEMSTONE Modules can be performed through the procedures of making masks from images and defining programs in the Arithmetic menu and then obtaining the spatial distribution and quantitative statistics.

With the interface between GEMSTONE and ARC/INFO, the results of image classification can be transferred to ARC/INFO as a new thematic overlay for further analysis or for high quality plotting. Once the transformation is finished, comparisons of image classification results can be carried out using functions of ARC/INFO GIS on coverage manipulations to identify readily changes in land use/land cover. Thus the major objective of monitoring changes in land use/land cover is achieved. Furthermore, the incorporation of GIS allows the integration of remote sensing analysis and other data stored in the system. For example, using the coverage of parish boundaries and the transformed thematic overlay of image classification, a detailed study of one parish was carried out. Areas of changes in woodland and trees revealed by imagery analysis can then be compared with that of parish summaries although caution needs to be exercised because of the existent errors in the changes product and the inaccuracy of farm woodland in the agricultural returns.

The comparison of classification results and change detection exercise are mainly presented in Section 5.5 of Chapter 5.

3.3.3 Integration of different approaches

A combination of different data sources is required for an integrated study of land use. They work both in parallel and supplementarily. Based on the results obtained from what has been described in Sections 3.3.1 and 3.3.2, the inter-relationships between the different data sources and different approaches can be explored.

3.4 Evaluation and Conclusion

To complete and justify the research, the approach must be evaluated in terms of efficiency or effectiveness, which includes evaluations of the viability and application of the methodology and of different roles of different data sources. These aspects are reflected in the following chapters, in particular Chapter 6 and Chapter 7.

In sum, this chapter attempted to elucidate the adopted data sources and methods for this research. It covered the selection of the Lammermuir Hills in South-East Scotland as a study area. The major data sources of parish summaries, Landsat images and other cartographic data were also evaluated in terms of their availability, reliability, appropriateness and how they were used for this research. Procedures on how to achieve the major objective of monitoring changes in regional land use/land cover with a combination of agricultural statistics and remote sensing analysis have also been presented and justified where appropriate. The inter-relationships between different data and methods in the study are hoped to be established and revealed as the work proceeds.

CHAPTER IV

AN ANALYSIS OF THE PARISH SUMMARIES FOR EAST LOTHIAN AND THE LAMMERMUIRS 1947-1987

Government intervention has played an important role in shaping British agriculture and thereby affecting rural land use changes, particularly during the post-war period.

After the Great Agricultural Depression, government control of the foreign competition and regulation of the home market were undertaken through implication of different agricultural Acts during 1930s and 1940s. They practically led to the initial abandoning of the Free Market (Robinson, 1988:PP147-149). Then the 1947 Agriculture Act controlled British agricultural policy until entry to the EEC in 1973. The principal objectives of the policy were to ensure national food supply by expanding agricultural output while making efficient use of domestic agricultural resources. The policy operated by means of marketing boards with a guaranteed price system. Thus, free market prices were supplemented with direct payments by the government to the farmers.

The Common Agricultural Policy (CAP) of the EEC tended to exaggerate some of the trends already established since 1947, with important implications for both the economic and ecological structures of agriculture. British government continued its commitment to support and regulate farming so as to prevent any shortage of food in the domestic market. Meanwhile, government control has also operated through an infrastructure of research, advisory and educational services. Growth of industrial farming and mechanisation and the intensification of farming have been formed as a result of influences of government policies and have contributed to the changes in rural land use (Bowler, 1985 and Robinson, 1988). Loss of agricultural land to other uses has been the consequence of the spread of the urban area and the decline of rural population. The chief differentiating feature of British agriculture remained the distinction between arable farming and cattle and permanent grassland (Robinson, 1988).

Some of these features of land use change underlining the government influences are reflected in the analysis of the parish summaries for East Lothian and the Lammermuirs from 1947 to 1987.

4.1 Introduction

In general, rough grazing, improved farmland and woodland constitute the three major land use types over much of the U.K. uplands (Wathern *et al*, 1988). However, the balance between these land use types has fluctuated throughout the post-war period. Previous studies (*e.g.*, Wrathall, 1988) have shown that U.K. farmers readily adapt their utilisation of land in response to financial incentives offered by the central government. In the rapidly changing economic and political environment of the post World War II years, there have been many changes in the pattern of land use. Expansion of cultivation and afforestation is usually the main cause of changes in land use and results primarily in the loss of areas of rough grazing. As shown in Table 4.1, until 1987, a major transfer of agricultural land in Scotland was to large scale forestry developments.

Since the 1950s, afforestation has been increasingly concentrated in upland Britain, especially in Scotland (Mather, 1978). Private afforestation has also been influenced by fiscal forestry policies. Figure 4.1 shows the percentage distribution of state afforestation 1945-1987. It can be seen that almost two thirds of the new planting took place in Scotland. A similar trend is also shown for private planting in Figure 4.2. Indeed, "much the most important single trend in hills and upland land use to be observed since 1945 is the substantial transfer of land out of hill farming into forestry" (Eadie, 1984).

Apart from the widespread afforestation, the national statistics on land use for Great Britain show that areas of wheat and barley increased rapidly from 1945 to 1982 whilst those of potatoes decreased (Table 4.2). These changes generally corresponded with price fluctuations. Similar agricultural trends exist in Scotland (Table 4.3). Barley has greatly

Table 4.1 Transfers of agricultural land to other uses in Scotland (Hectares)

Net annual average transfers to:	1960-65	1965-70	1970-75	1975-80	1980-85	1986-87
Forestry	17870.1	19452.0	24073.2	17947.4	13273.0	14591.2
Urban & Industry	1861.2	2295.3	1219.6	1084.1	536.2	269.3
Recreation	264.7	270.5	302.7	133.2	1775.6	256.3
Water & Mineral	360.6	257.3	316.1[d]	138.4	189.9	101.8
Service department	65.2	31.5[a]	10.3[d]	7.7[c]	136.9[c]	17.4
Others	283.3	428.3	526.2[a]	49.6[b]	66.3[d]	62.8
Total	20705.1	22671.9	25383.3	19327.6	15910	15298.8

Note: (a). Gain
(b). 2 year average
(c). 3 year average
(d). 4 year average

Source: DAFS Agricultural statistics

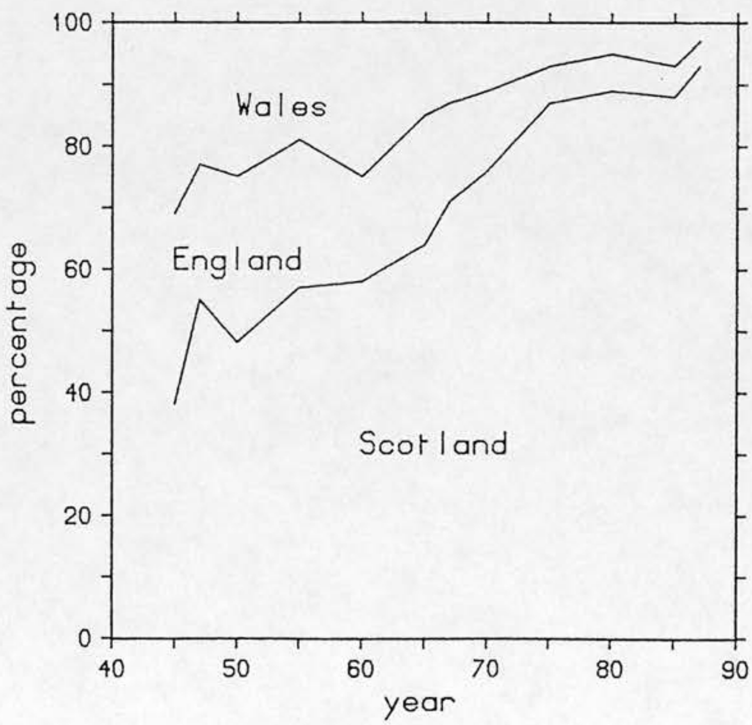


Figure 4.1 Percentage distribution of state afforestation 1945-87
Source: Compiled from Annual Reports of the Forestry Commissioners.

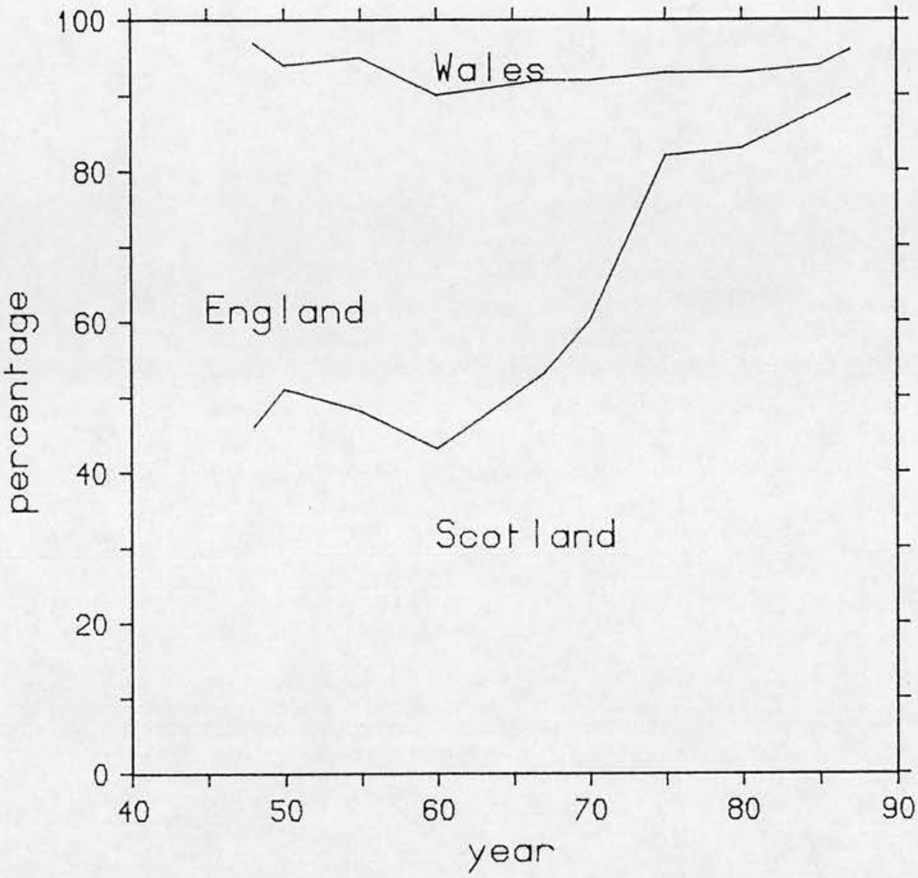


Figure 4.2 Percentage distribution of private afforestation 1948-87
Source: As Figure 4.1

increased its sown acreage and become the most widely grown farm crop. Reflecting its value as a source of animal feed on many types of farm, barley growth is no longer restricted to these areas where it was traditionally important, *e.g.*, East Lothian, Berwickshire and Roxburghshire (Dawson, 1980). In contrast, the areas under oats, potatoes, turnips and swedes have decreased.

The Lammermuir Hills area in South-East Scotland, as a test location for this research, covers different land use zones from upland to lowland and has experienced such major changes as afforestation of former moorland, conversion of rough pasture to improved grassland and expansion of arable land towards the upland over the past four decades. To further analyse these changes in land use, the statistical data from the parish summaries for the selected sixty-one parishes have been examined in the following sections.

Table 4.2 Area of principal crops: Great Britain (Hectares)

Three year average	Wheat	Barley	Oats	Potatoes
1945-47	890309	849841		485623
1950-52	930778	809372		404686
1955-57	849841	971246		323749
1960-62	809372	1456870		283280
1965-67	971246	2266242	364217	242812
1970-72	1052184	2185304	323749	242812
1975-77	1092652	2185304	202343	202343
1980-82[a]	1456870	2266242	121406	161874
1985-87	1942493	1861556	121406	161874

Note: (a). average of two years only.
Source: Agricultural Statistics: U.K.

Table 4.3 Area of principal crops in Scotland (Hectares)

Year	Barley	Wheat	Oats	Turnips & Swedes	Potatoes
1956	79749	30992	331418	108434	65439
1960	102894	38258	275429	98822	61629
1965	226031	39826	175181	75499	57332
1970	286518	39631	125194	56848	43895
1975	368553	27634	66019	55233	30598
1980	443544	25643	38990	44902	35299
1985	415688	81576	30086	35991	33252
1987	386755	103598	28823	31745	28960

Source: DAFS Agricultural Statistics.

4.2 Cartographic Representation of the Parish Summaries

A detailed map series obtained from CAMAPGB1 is presented in Appendix 2. Characteristics of the spatial distribution for each variable and the integrated pattern of land use in the study area were revealed by visually and statistically interpreting the map series.

4.2.1 Agricultural land under crops and fallow

Proportions of total agricultural land under crops and fallow have been increasing since 1960 as demonstrated by the mean, maximum and minimum values of the sixty-one selected parishes. The general pattern of the spatial distribution of these proportions was similar over different years. Throughout the study period of forty years, most parishes with less than 40 per cent of land for cultivation were those containing part of the Lammermuir Hills. The further a parish is from the Hills, the higher its proportion of cropland. The East Lothian Plain and the Berwickshire Merse, where the most favourable agricultural land exists, were the areas of intensive arable farming. Apart from this general pattern, it was found that the upper limit of parishes with a high proportion of land under cultivation had been advancing towards the Hills and the number of these parishes had also been increasing. However, most of the parishes on the Lammermuir Hills had maintained their land in tillage below 40 per cent of the total agricultural land. Intensification of arable farming, *i.e.*, the increase in the proportion of arable land, had mainly taken place in the East Lothian Plain and the Berwickshire Merse, which indicated that more agricultural land was in cultivation within these areas. By 1984, twenty-three parishes in these areas had over 70 per cent of their agricultural land under cultivation. A maximum of 94.6 per cent was reached in Aberlady in 1986.

To help understand changes within arable farming, proportions of land in tillage under the principal crops of winter wheat, barley, oats, potatoes, oilseed rape, and turnips and swedes respectively were mapped.

Pre-1947, **winter wheat** production had been concentrated in the East Lothian Plain. Before 1960, most parishes had less than 10 per cent of arable land in wheat production while no more than 20 per cent of land in tillage was used for wheat growing in all parishes. However, the area under winter wheat has increased since 1960, especially in the East Lothian Plain and the Berwickshire Merse. Parishes with more than 10 per cent of tillage under wheat covered most of the study area in the mid-1980s, even on the north-east part of the Lammermuir Hills. The boundary for parishes with higher proportions of winter wheat has been extended towards the Hills. This tendency is especially distinct from 1984 onwards when there has been a great expansion in winter wheat growing. By 1987, twenty-eight parishes of the selected sixty-one had over 30 per cent of their arable land under wheat production. This accelerated expansion in areas under wheat reflects the significant increases in wheat prices since the U.K. joined the EEC (Holderness, 1985).

Barley is an important cash crop and has long been a major use of Scottish arable land (Dawson, 1980; Holderness, 1985; Stamp, 1941). Its traditional importance in East Lothian and Berwickshire has been maintained. However, the substitution of barley for oats and roots in cattle feed and the improved varieties of grain suitable for cultivation in cool, temperate latitudes have brought a wide distribution of barley growing with its considerable value in supplying feed for stock. Barley is no longer restricted to those areas where it was of traditional importance, although its largest acreage continues to be to a certain extent in sheltered locations, *e.g.*, Lauder parish. The substantial change in the distribution of barley is shown both in its spatial expansion and the increase in quantity of cultivation. By 1976, all parishes in the study area had more than 30 per cent of their arable land under barley production. This reached a peak in 1979 and 1980 when all parishes had over 45 per cent of their tillage under barley growing and fourteen parishes had over 75 per cent of their tillage under barley. Meanwhile, there has been a tendency towards increased barley growing at higher altitudes. However, a slight drop in barley acreage appeared after 1984. This reduction in barley acreage occurred mainly in the lowland areas where barley gave way to wheat growing, again reflecting price differentials.

Growth of **oats** had also been a major use of arable land in South-East Scotland, although less important than barley and winter wheat. Oats were traditionally a major crop and occupied the largest acreage of all crops grown on the hills, since it was more tolerant than other cereals to adverse climatic and soil conditions (Stamp, 1941). Oats also had the advantage of high bulk yields per hectare. It can be seen from the map series that the most tillage sown for oats was in parishes above c.600 feet such as Longformacus and Cranshaws. Oats can even be grown at 1000 feet if the aspect is suitable. In 1960, more than ten parishes had over 40 per cent of land in tillage under oats. These parishes were mainly on the higher ground. At lower levels, oats had to compete with barley and wheat. Therefore, the spatial pattern of the distribution of oats reflected the operation of this competition, with only limited cultivation of oats in the lowlands. But this pattern disappeared when areas sown under oats declined greatly in the 1970s. By 1979, almost all parishes had less than 10 per cent of their arable land under oats. The mean value for the proportion of tillage under oats for the sixty-one parishes decreased from 28.47 per cent in 1947 to 1.63 per cent in 1987. Only a few parishes in the uplands still keep oats in cultivation to provide meal for both human and animal consumption. The acid soils of hill areas in South-East Scotland provide almost the last refuges of this once widespread crop. One major substitute for oats in the upland parishes has been barley (Dawson, 1980).

Potatoes, another important cash crop today, were not of much importance before 1940 (Stamp, 1941). They were mainly grown for domestic use, greater output being limited by high labour requirements. However, with the developments in improved machinery, potato-growing has become more concentrated. Intensive farming of potatoes occurs in the East Lothian Plain and the Berwickshire Merse. In 1947, around thirty parishes had more than 8 per cent of their arable land under potatoes; some even reached 20 per cent. This situation remained until the end of the 1960s. Then the crop acreage declined because of the following two major reasons. First, potatoes suffered from competition with protein rich, more expensive or more fashionable foodstuffs as income rose. Second, the yield of potatoes per hectare increased, *i.e.*, more output of potatoes from less land. Since then, most of the parishes in the study area have used less than 2 per cent of land in tillage for growing potatoes. Only a few parishes in the East Lothian Plain have kept over 8 per cent of tillage under potatoes. In general, the fall in acreage of potato planting, supplemented by an increase in yields, has roughly kept pace with the current demand.

Turnips and swedes were once the keystone of husbandry in Scottish farming, after the introduction of turnips in the eighteenth century (Stamp, 1941). As important fodder crops, they solved the problem of winter feeding to a large extent. They also played the role of replacing fallow in crop rotations. Like oats, turnips and swedes were widespread over the study area before the 1960s. They were grown almost exclusively for home use and formed the basis of winter feeding for both cattle and sheep. In 1960, more than thirty-six parishes out of the selected sixty-one parishes had over 12 per cent of tillage under turnips and swedes. However, there has been a great fall in the acreage of these crops since then. They have played only a small part in modern tillage regimes. By 1987, thirty-four parishes had less than 3 per cent of tillage for turnips and swedes while only Heriot parish used over 10 per cent of tillage for turnips and swedes. They now mainly form a residual catch crop on small mixed farms. This fall in acreage may be due to the loss of the advantages of turnips and swedes as fodder crops when feed barley became a major agricultural product.

Winter oilseed rape is one of the new crops to Scottish farming, being made attractive to farmers by the price supports of the Common Agricultural Policy (Wright, 1985). There has been a considerable increase in the acreage of this crop within eastern Scotland recently. Some of the reasons why the rapid expansion has developed are as follows. First, the cultivation of oilseed rape is suitable in cool temperate climates, with a potential for expanding production (Wrathall, 1978 and Robinson, 1988). Then the commodity price rise has made it favourable to farmers. In order to reduce the EEC's dependence on imported vegetable oils, the EEC set attractive support prices to encourage farmers to grow rapeseed. An extra payment has been made to the oilseed crushers to enable them to use the EEC rapeseed. Thus the average market price has risen steadily to make oilseed rape a valuable cash crop in its own right (Wrathall and Moore, 1986) and provides farmers with a suitable commercial outlet for their crops. The introduction of new crop varieties has also enhanced its value. Also, as a break crop, winter oilseed rape can be produced using normal cereal growing equipment and therefore has little effect on the fixed costs of the farming business. Existing machinery, with minimal modification, can be utilised for its cultivation and harvesting. In addition, winter oilseed rape fitted in well with the new cropping systems with an increased area sown to winter barley in the late 1970s and the early 1980s. Rape seed improves the structure and fertility of the soil which benefits the following cereal crop and thus it has proved a highly profitable break crop, especially on the larger farms (Wrathall, 1978 and Robinson, 1988). In Scotland, with harvest in early August, winter barley provides an ideal entry for winter oilseed rape one or two weeks later whilst the August harvesting of oilseed rape also provides a suitable entry for winter wheat or a return to winter barley (Wright, 1985).

The parish summaries for Scotland did not introduce a separate category for oilseed rape until 1984, although the first adoption of winter sown oilseed rape started in 1979/80 (Robinson, 1988). This made it difficult to examine changes in the production of the crop. However, even with the four years' data from 1984 to 1987, it can be seen that there has been a rapid increase in winter oilseed rape growing within the study area. In 1984, most parishes had less than 3 per cent of their tillage land under oilseed rape and none of the parishes used more than 8 per cent of arable land for winter oilseed rape. But by 1987, only twelve parishes, which are mainly situated on the hills, had less than 3 per cent of land in tillage under oilseed rape while three parishes (Mordington, Langton and Polwarth) had more than 12 per cent. As a new crop in the arable farming system, the distribution of oilseed rape generally follows the pattern of arable farming and those for winter barley or winter wheat. The main concentration of oilseed rape was on land below c.325 feet (100m), especially on land with good artificial drainage (Robinson, 1988).

4.2.2 Agricultural land under farm woodlands

Scotland offers climatic conditions suitable for the growing of conifers and certain softwoods, and much of its widespread podzolic soils support productive boreal forests. Also, there is more poor and relatively unproductive uplands in Scotland than in England. More than half of the Forestry Commission replanting since the 1950s has taken place in Scotland, especially in the Southern Uplands (Eadie, 1984; Murray, 1973 and Tranter, 1978). New planting has been divided roughly equally between the Forestry Commission and private owners.

There has been considerable planting by private land owners as a result of the advantageous treatment of investment in woodlands and fiscal policies, mainly through the grant-aid paid since the Second World War, although there have been changes since 1988.

Under the 1947 Forestry Act, land owners could enter into Forestry Dedication Covenants in which, without prior content from the Forestry Commission, land could not be used other than for forestry (Robinson, 1988:P205). Since then, the Forestry Commission has offered technical and financial aid to private owners for dedicated land. The Dedication of Woodlands Scheme provided a planting grant for forestry land under the management supervision of the Commission. Annual management grants were also paid for new and established woodland. Tax benefits were another major factor. For income tax, losses on investment during the early years of a forest could be offset against the owner's income from other sources. Standing timber remains exempt from capital gains tax. For Estate Duty, the land qualifies for the same 45 per cent abatement of duty as does agricultural land, and no duty is payable on the timber until it is felled or sold (Lea *et al*, 1977:P150). Then the policy statement of 1958 announced that "in deciding where planting will take place, special attention will be paid to upland areas, particularly in Scotland and Wales, where expansion of forestry would provide needed diversification of employment and important social benefits". Therefore, acquisition and afforestation have become increasingly concentrated in Scotland and Wales since then.

Those ideas were extended under the 1967 Forestry Act with a series of grants to encourage private forestry. For example, planting grants were available under the Approved Woodland Scheme, although there was limited Forestry Commission involvement in management decisions. Similar provision was also made for Small Wood planting.

In the 1970s, following the 1972 White Paper on Forestry, the Dedication Scheme was suspended, later with a reduced level of grant aid for most private woodland owners. Then Estate Duty was replaced by Capital Transfer Tax. All those made investment in Forestry no longer so attractive as in the 1960s.

However, it has been revived following the 1981 Forestry Act and the establishment of a Forestry Grant Scheme for the private sector. Further positive steps towards the encouragement of more woodland on farms were taken in early 1987 in the form of suggestions for a Farm Woodland Scheme (Robinson, 1988:P205). For instance, "a major new initiative on the farm forestry front--with a £10 million a year package--will see payments of up to £125 a hectare made available to farmers to grow trees as part of their farming enterprise" (Jopling, 1987). Thus, post-war afforestation in Britain has proceeded under a complex set of influences, and planting by private owners has been responding well to the incentives of fiscal policies.

With regard to South-East Scotland, only small blocks of forestry land occur, having an average extent of less than 20 hectares, as a result of competition with agriculture for available land (Lea *et al*, 1977:P151). The more productive upland here remains in agricultural use, thereby restricting afforestation.

Regular data on farm woodlands at parish level started in 1960 in the parish summaries. Therefore proportions of land under farm woodlands were mapped for the selected years covering the period from 1960 to 1987. It can be seen from the map series that woodlands on farms comprise only a small proportion of total agricultural land, but the area under farm woodlands has been increasing steadily. In 1960, there was only one parish (Legerwood) with 6 per cent of its agricultural land under farm woodlands. However, fourteen parishes have maintained more than 4 per cent of their total agricultural land for farm woodlands since 1985. Some parishes (*e.g.*, Humbie, Ayton and Eyemouth) had over 8 per cent of the agricultural land under farm woodlands.

The majority of farm woodland is in those parishes which are located predominantly on the upland fringes. In order to demonstrate the spatial changes in farm woodlands, Figure 4.3 was produced using data for 1960 and 1985. It shows that from 1960 to 1985, most parishes had an up to 1 per cent increase in the percentage of total agricultural land under farm woodlands. Four parishes had more than 4 per cent increases (Fala and Soutra, Ayton, Eyemouth, and Oldhamstocks). It is noticeable that those parishes where major increases in farm woodlands took place were not actually situated on the Hills but in the adjacent lowland or upland areas. This is because unplantable land is mainly on the Hills, limited by the exposure to wind and by poor soil. Also, it is partially an extension of the pre-existing pattern of private woodland. Those pre-existing areas offer relatively attractive tree growth rates and a high percentage of plantable land. Thus the best financial returns are often obtained there. Furthermore, it could be subject to the likely viability of a wood-

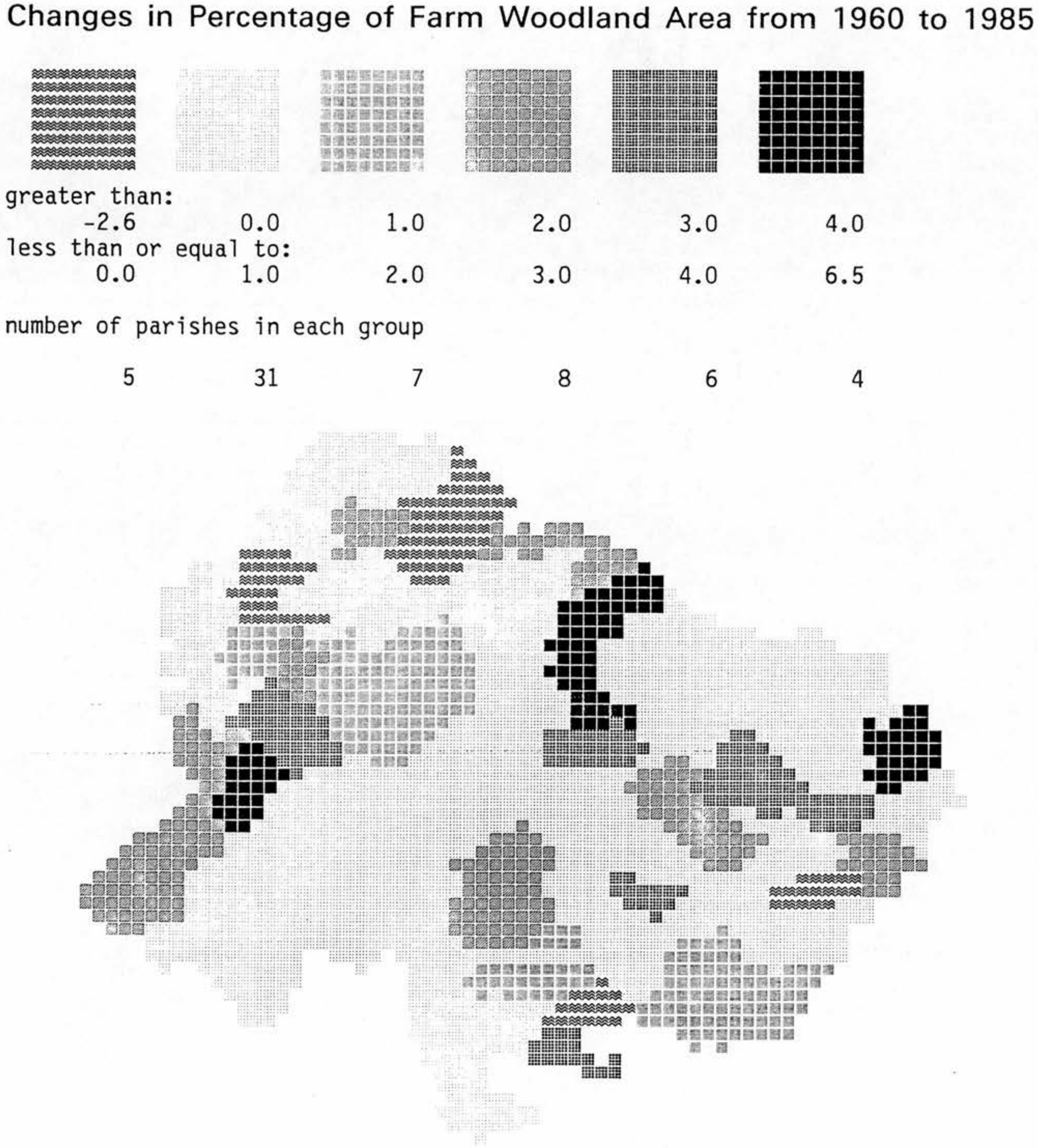


Figure 4.3 Changes in percentage of farm woodland 1960-85
Source: DAFS Agricultural Statistics for the 61 selected parishes.

using industry in the lowland or upland areas.

Apart from the rapid increase in farm woodlands, there has been quite a lot of planting by the Forestry Commission which has provided the main impetus for reafforestation through its forestry programme (Lea *et al*, 1977). Rough grazing has been the major source of land for planting. Extensive land purchase has made the Forestry Commission the largest single landowner in Scotland. Unfortunately, no census data of non-farm woodlands and trees is available at parish level. Census data available only at district level show that in 1947 no land in East Lothian and only 425 hectares in Berwickshire were planted for woodlands and trees by the Forestry Commission while by 1982, this had been increased to 1275 hectares in East Lothian and 962 hectares in Berwickshire (Table 4.4). The location of this forestry will be examined in the analysis of the Landsat imagery.

Table 4.4 Census of Woodland and Trees for East Lothian and Berwickshire (Hectares)

		East-Lothian	Berwickshire
1982:			
	Total	5307	5705
	Forestry Commission	1275	962
	Dedicated & Approved	2107	2513
	others	1925	2230
1947:			
	Total	4263	6254
	Forestry Commission	0	425
	Private	4263	5829

Source: Forestry Commission, The Department of Forestry.

4.2.3 Agricultural land under rough grazing

Map series of proportions of agricultural land under rough grazing showed clearly that parishes with the most rough grazing land were those situated on top of the Lammermuir Hills and the upland zone whereas those on the East Lothian Plain and the Berwickshire Merse had the least land for rough grazing. Over time, the area of rough grazing has been changing but its basic pattern of spatial distribution has been static. "Generally speaking, land improvement has been discouraged on heather moorland" (Eadie, 1984). The moorland core has always been under extensive management. For instance, Longformacus and Whittingehame have always had more than 70 per cent of their agricultural land under rough grazing. Much of the improvement in the quality of grassland resources, *e.g.*, re-seeded pasture, took place in the fringe area which had been changing between moorland, farmland and forest. What happened in Bunkle and Preston parishes is a good example.

In order to elaborate the changes within hill farms, cattle and sheep densities were mapped as well. **Cattle** production has been an important segment of British agriculture since the war (Holderness, 1985:P63). The system of production of beef by intensive feeding of barley to Friesian calves to fatten them within the year has been widely adopted by arable farmers who produce a large surplus of barley and who have the resources to build intensive fattening sheds. In general, therefore, cattle raising has been more intensive on the East Lothian Plain and the Berwickshire Merse. Prior to 1960, most parishes within the study area had cattle densities of less than 40 per hectare; many parishes on the Hills had less than 20 cattle per hectare while there were no parishes with more than 80 cattle per hectare. Cattle raising has increased greatly since then and has been expanding towards the Hills. A far more widespread distribution of cattle was apparent by the 1980s. Most parishes had a density of more than 20 cattle per hectare. Some lowland parishes had densities of over 140 cattle per hectare. Only those parishes on the moorland, such as Longformacus and Whittinghame, retained a low level of cattle raising.

Sheep production is mainly concentrated in the upland zone. The lowest densities of sheep were found in those parishes situated in the East Lothian Plain, *e.g.*, Dirleton, Aberlady and Athelstaneford, where arable farming was dominant. Sheep rearing has been increasing and expanding greatly during the past four decades, encouraged by compensatory payments as part of the EC's Less Favoured Areas Scheme. By 1987, twenty parishes had more than 300 sheep per hectare, with 487 per hectare in Cockburnspath. Although sheep rearing was the major enterprise on rough grazing land, parishes with the most rough pasture did not necessarily hold the highest density of sheep, which may be due to the fact that grassland conversion occurred on the rough grazing land in order to sustain higher sheep numbers. It is also because rough grazing can only support limited numbers of sheep per hectare. Intensification of sheep stocking has mainly taken place where the quality of grassland resources and the production of grass on upland farms has been improved. Sheep have been the most important stock kept in the upland zone and almost the only farm animals on rough grazings. Apart from the moorland and mountains proper, sheep are typical of fringe areas between upland and lowland.

4.3 Temporal Changes in Major Land Uses

The balance between arable and grass on the cultivated area is an important yardstick for agricultural production. For this study, the temporal changes in the acreages of arable land, grassland, farm woodland and rough grazing were presented and compared. Further trends of changes within arable land were also shown by figures for some of the crops.

In Scotland, only about one third of the cultivated area has generally been in grass and the remainder has been kept in tillage. Figure 4.4 shows that in 1947, 160,219 acres were under crops and fallow with 156,718 acres in grassland. The area under tillage fell until 1960 when only 139,890 acres were under tillage, by comparison with 190,593 acres of grassland in that year. After this fall, the increased use of cereals for livestock feed reversed these figures. In the 1960s, "when the tide of official opinion had set towards import-saving self-sufficiency" (Holderness, 1985:P43), the acreage under crops increased greatly and soon exceeded the 1947 level. From then on, land in tillage continued to increase, determined by the profitability or favourable EEC support policies for arable farming post-1973. By 1987, 202,653 acres were under crops and fallow whereas only 114,021 acres were in grassland. These figures accord well with those for the whole of Scotland. By studying the figures for some of the individual crops, it is easy to see that the increased acreage under crops was chiefly through increased cereal cultivation (Figure 4.5 and 4.6).

Barley production has been predominant in that its total area has remained two to four times as much as the acreage of wheat. From 1950 the area under barley has increased, even during the period from 1947 to 1955 when wheat cultivation was in modest decline due to the developing world glut after the Korean War (Holderness, 1985:P49). The rapid

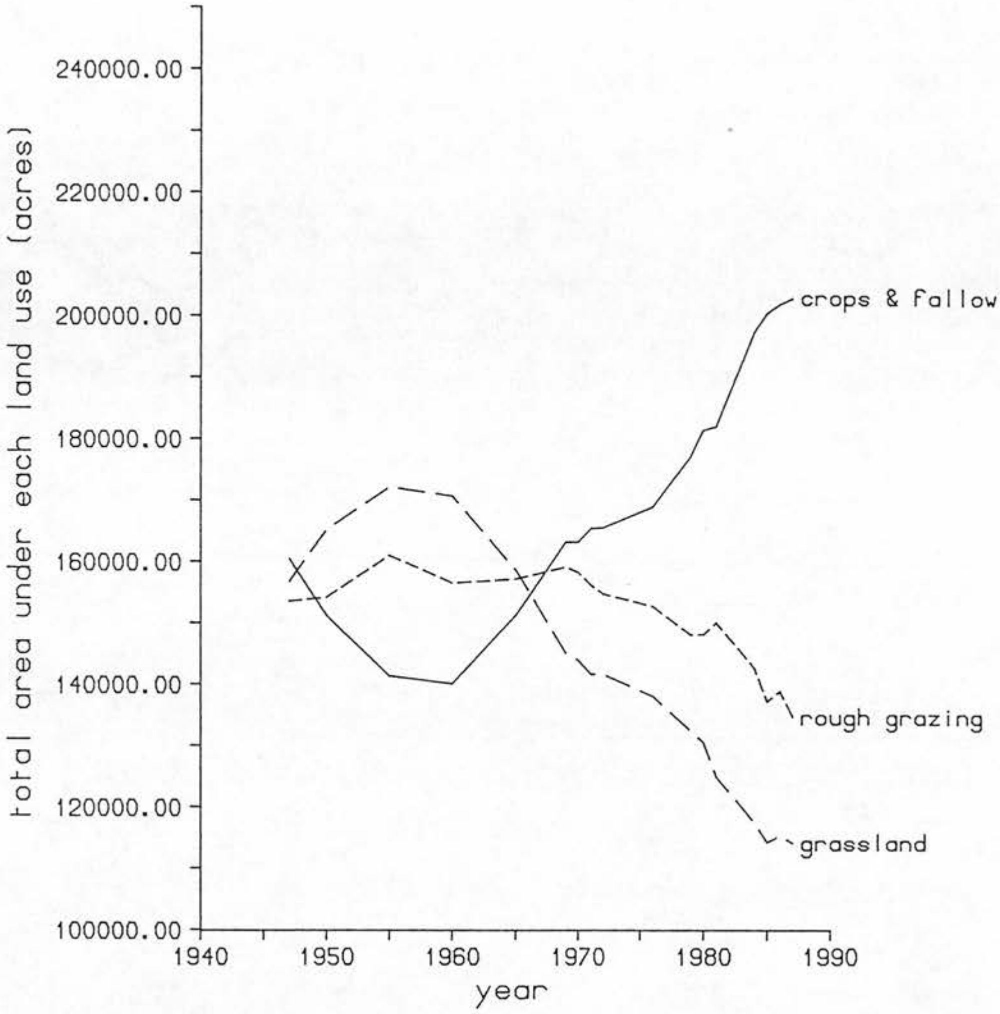


Figure 4.4 Temporal changes in total areas of arable land, grassland and rough grazing
Source: Compiled from DAFS Agricultural Statistics for the 61 selected parishes.

increase of barley growing continued until the 1980s, as a product of several factors. Among them are the growing demand for malting barley and the importance of feed barley. The improved techniques of malting and varieties of grain also contributed to the barley expansion. Almost all the increase in arable land during 1960 to 1980 was attributable to the growth of barley. This increase was mainly at the expense of oats, grass and some root crops (Dawson, 1980).

Recovering from a modest decline after the war, wheat growing increased during the 1960s and remained stable until the early 1980s. There has been another dramatic increase since 1981, supported by high intervention prices in the Common Agricultural Policy.

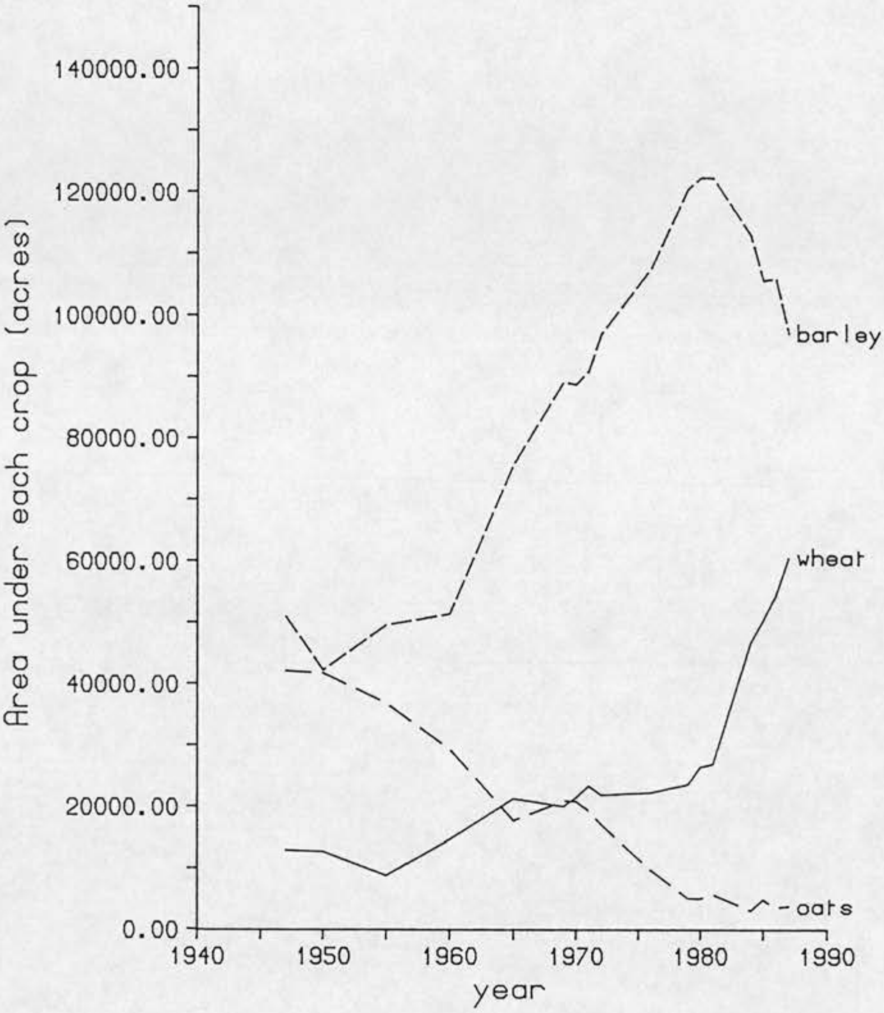


Figure 4.5 Temporal changes in areas of barley, wheat and oats
Source: As Figure 4.4

The expansion of the wheat area has been made to a large extent at the expense of a reduction in barley growing during the 1980s.

The acreage of oats has declined sharply during the past four decades as a consequence of the increased area sown to barley. The present level of the acreage of oats in the study area is less than 10 per cent of that forty years ago. Similarly, the area under turnips and swedes has decreased following the loss of their importance as fodder crops.

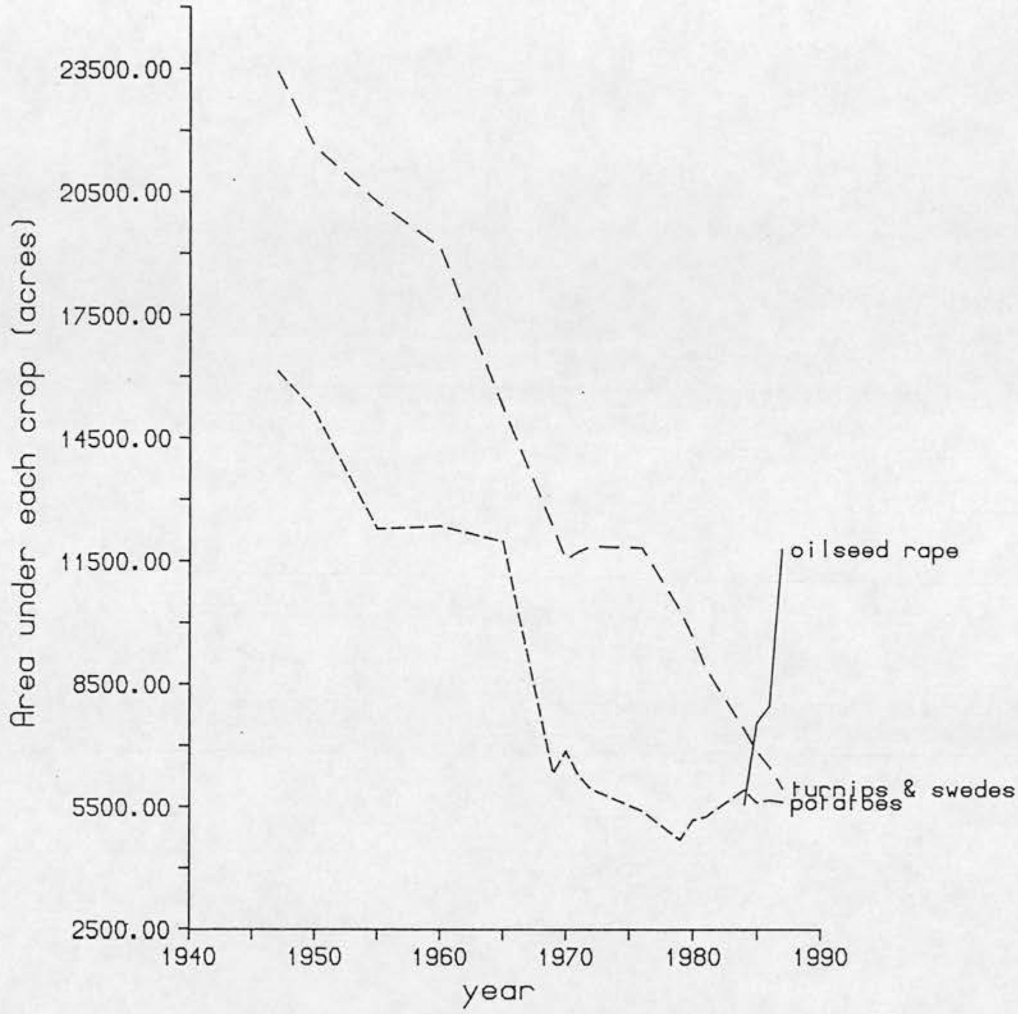


Figure 4.6 Temporal changes in areas of turnips and swedes, potatoes and oilseed rape
Source: As Figure 4.4

The area under ware potatoes has also declined over the past four decades as they suffered from competition with other foodstuffs. Moreover, the risk of competition from nearby continental sources has been even greater with integration into the EEC. The area under potatoes has been stable since the 1970s, whilst the increase in yields of potatoes has kept pace with demand.

As a new crop in Scottish farming, winter oilseed rape has enjoyed a considerable increase in its acreage. During the four years from 1984 to 1987, the acreage of oilseed rape doubled within the sixty-one selected parishes. As analysed in Section 4.2.1, the popularity of the crop has been a result of two main factors, *i.e.*, its intrinsic value as a break crop in the intensive cereal rotation system and the financial support provided for the crop under the Common Agricultural Policy of the EEC (Robinson, 1988; Wrathall and Moore, 1986; Wright, 1985).

The area of farm woodland has been increasing steadily since 1960 and especially after 1972 (Figure 4.7). Although this increase has taken only a small proportion of total agricultural land, its rate of change is significant. The acreage of farm woodlands in 1987 was 75 per cent more than that in 1960.

As for rough grazing (see also Figure 4.4), its total area fluctuated slightly between 153,000 and 162,000 acres during the period from 1947 to 1970, but there was a great decline after 1970. The total reduction of rough grazing land reached nearly 25,000 acres between 1970 and 1985. This reduction was mainly due to its loss to the Forestry Commission for afforestation. The conversion of rough grazings to improved grassland was also a factor.

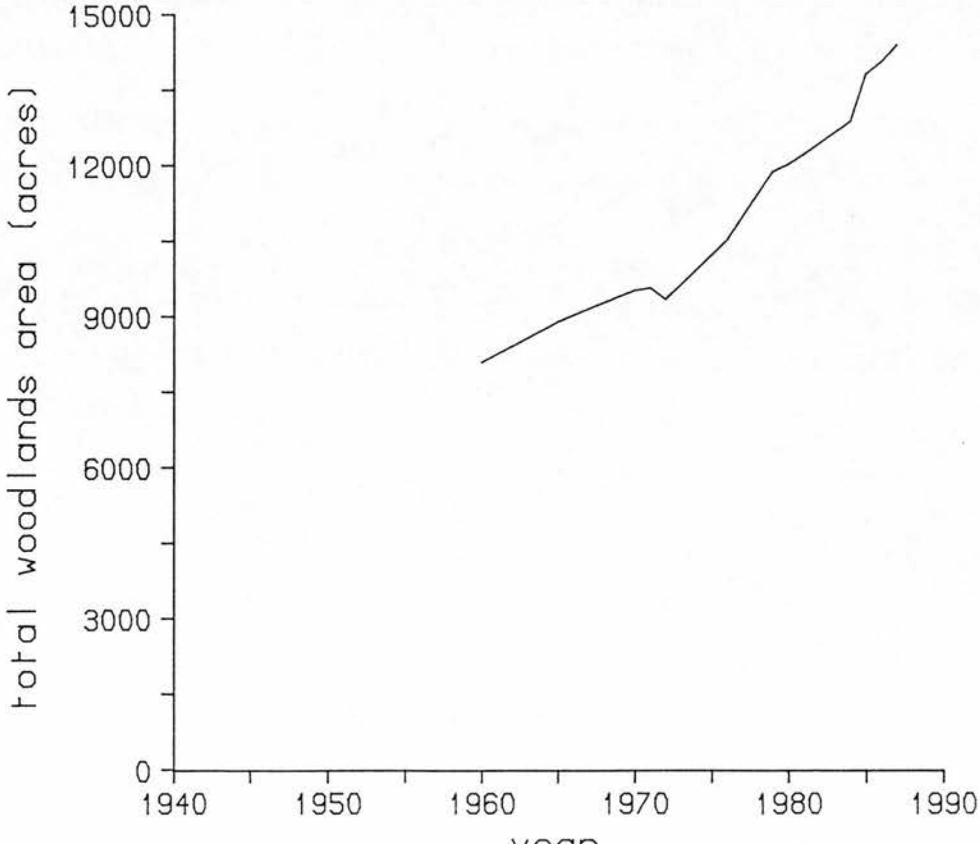


Figure 4.7 Temporal changes in areas of farm woodland
Source: As Figure 4.4

There was a rapid rise in total sheep production from 1947 to 1965, followed by a sharp decline afterwards (Figure 4.8). Hill sheep numbers declined significantly. Subsequently there has been a recovery in sheep numbers during the 1980s, resulting from the greater intensities of sheep raising on improved grasslands.

As for cattle production, this had been increasing from 1947 to 1976. This increase, especially after the mid-1960s, was linked to the intensive feeding of barley to fatten the calves within one year, which was widely adopted by the farmers who produced a large surplus of barley. However, the great increase has been followed by a reduction during the 1980s (Figure 4.9).

Figures 4.4-4.9 show changes in each variable during the past four decades. The total area under crops and fallow has been increasing, with the increased acreage under crops mainly occurring through the rise in acreage of barley and wheat. Moreover, the rapid rise in the areas under those crops was achieved at the expense of other crops, *e.g.*, oats, potatoes, and turnips and swedes. As a new crop, oilseed rape is playing an important role in the present farming system. One compensation for the loss of grassland to tillage has been the conversion of rough grazing land to improved pasture. Thus the maintenance or increase in sheep numbers can be explained despite the decline in the area of rough grazing. Apart from the conversion to grassland, there is evidence that the area of rough grazing has been transferred to farm woodland use or has been lost to the Forestry Commission for recent afforestation. The rapidity of the rise in farm woodland forms a striking characteristic of land use in the study area.

Finally, Figure 4.10 shows that the total area under agricultural land increased from 1947 to 1969. This may seem contrary to the national trend in that, nationally, agricultural land was lost to urbanisation and afforestation (Best, 1981). However, the increase may be a result of a flaw in the data source because the total agricultural land used in the parish summaries prior to 1960 was actually the sum of crops and grass and rough grazing. At that time, there were no records of farm woodland or other farm lands. Therefore, the increasing trend in total agricultural land during this period could be spurious, caused by the discordances of data over different years. These discordances in data collection have been largely overcome after 1960. Using the data from 1960 onwards, it can be seen that there

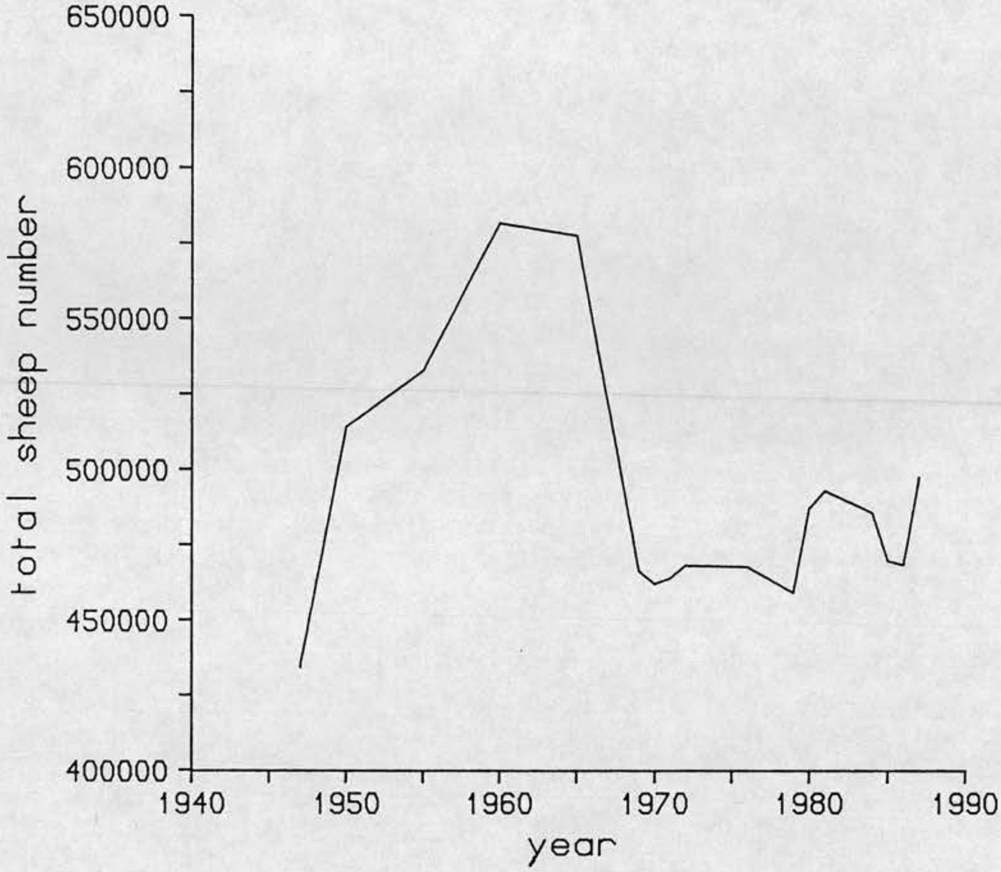


Figure 4.8 Changes in number of sheep
Source: As Figure 4.4

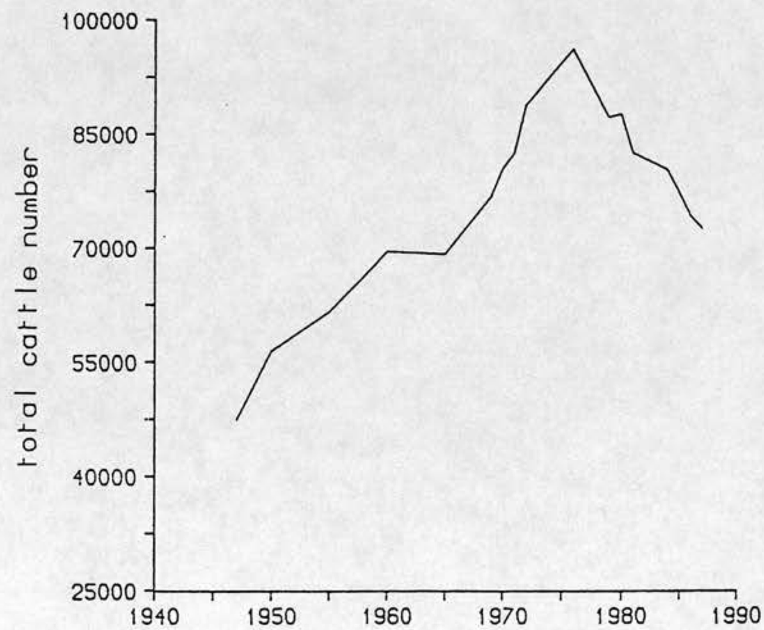


Figure 4.9 Changes in number of cattle
Source: As Figure 4.4

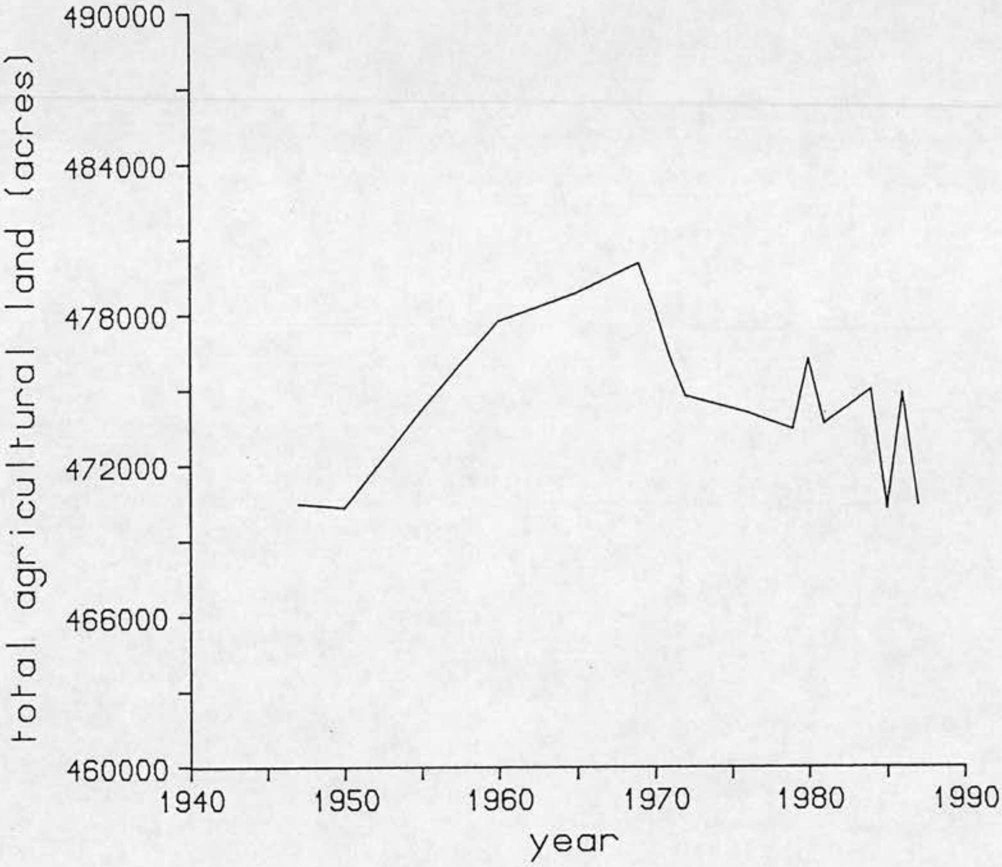


Figure 4.10 Changes in total area of agricultural land
Source: As Figure 4.4

has been a drop in total agricultural land, which is a reflection of the general change in agricultural land use at the national level, *viz*., agricultural land has been lost to urban development, afforestation and recreational use since the 1960s. Regarding the extent of loss, there is a tendency for the forestry sector to take the leading role while urban expansion has been lagging behind because of strong planning restrictions upon urban development.

4.4 Further Analysis on the Inter-relationships between Different Land Uses

A correlation analysis between different land use/land cover variables examines the inter-relationships quantitatively and clearly. Both a temporal analysis and a spatial analysis were explored in this research.

First, a correlation analysis was carried out between each pair of variables in terms of changes through time. The mean values for the sixty-one parishes over the seventeen years were used, for the proportions of arable land, rough grazing, farm woodland and grassland respectively. Figure 4.11 shows how these variables changed with time, and the correlation coefficients are enclosed between brackets next to each curve.

Strong positive correlations (significant at the 0.05 level) exist between: Time and Proportion of Arable Land; Time and Proportion of Farm Woodland, whereas significant negative correlation coefficients were obtained between: Time and Proportion of Rough Grazing Land; Time and Proportion of Grassland.

These results confirmed that percentages of agricultural land devoted to arable crops and farm woodland had been increasing for the past four decades whilst rough grazing land and grassland had been decreasing with time. In addition to analysing how the variables were related over time, they were also correlated for each of the seventeen selected years. It can be seen from Appendix 3 that for almost every year, significant negative correlation coefficients were obtained between cropland and rough grazing, but farm woodland did not have significant relationships with any other variables. Other inter-relationships discovered in the yearly correlation analyses for all the parishes are those between density of sheep and rough grazing (+), arable land and density of sheep(-), density of cattle and grassland (+), density of sheep and grassland (+). Individual crops and livestock were not used for correlation because the inter-relationships between them have been revealed in the last Section. The different types of cattle and sheep were also ignored due to the inconsistencies of the data.

Thus the following relationships can be established between different variables:

(1). Over time, proportions of agricultural land under cropping and farm woodland have been increasing whilst grassland and rough grazing have been decreasing.

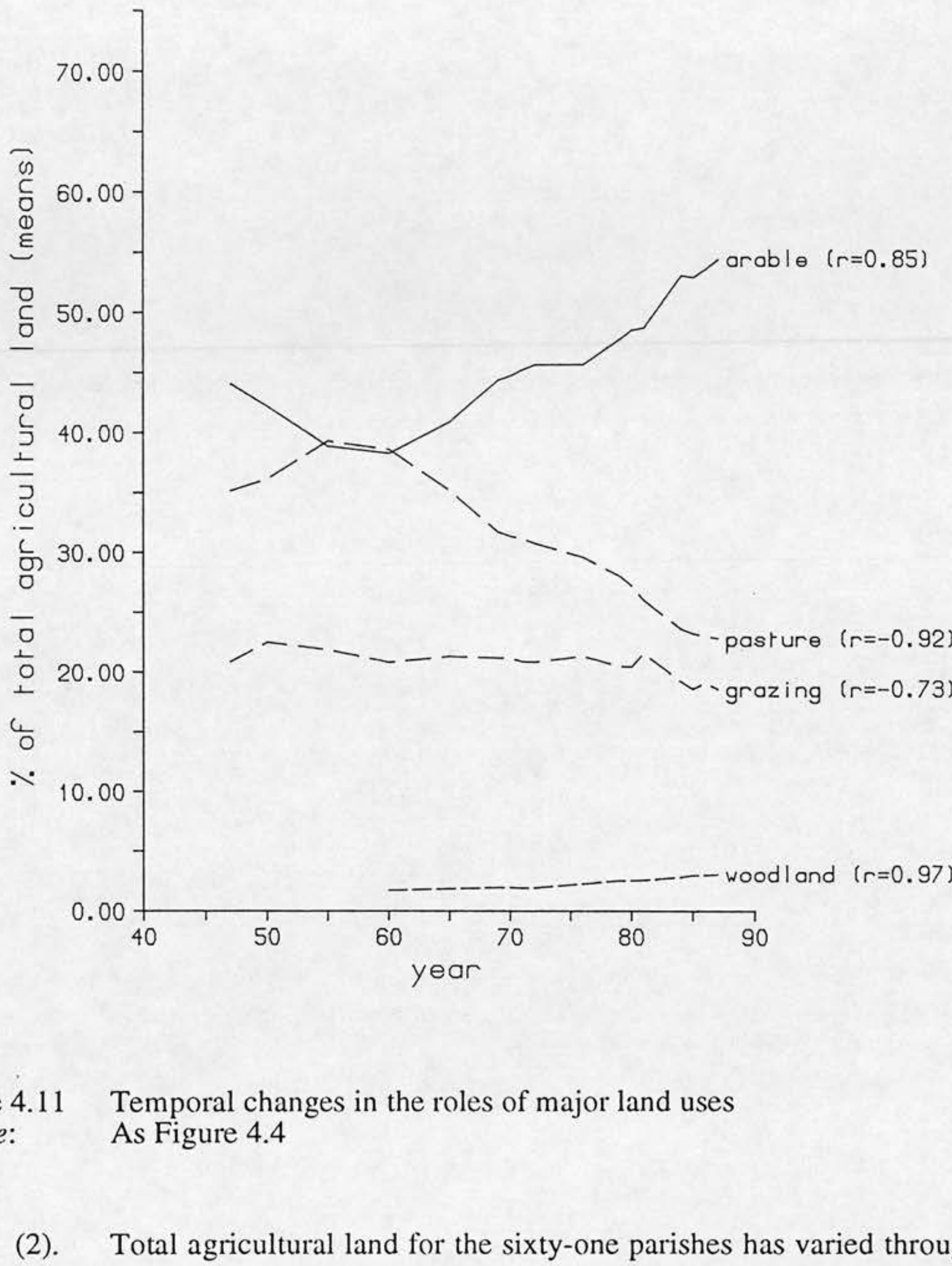


Figure 4.11 Temporal changes in the roles of major land uses
Source: As Figure 4.4

(2). Total agricultural land for the sixty-one parishes has varied through time. It has been decreasing since 1970, with transfers into afforestation, especially in the uplands and hills. Urbanisation on the rural-urban fringe also accounted for some losses but to a smaller extent.

(3). The loss of rough grazing land may have resulted from its conversion to improved grassland for intensive sheep rearing or from its sale to the Forestry Commission for afforestation while quite an amount of grassland has been reclaimed for arable crops. Therefore, cultivation, afforestation and rough grazing are competitors for land. The reduction in rough grazing land constitutes the main reason why total agricultural land appears to be decreasing. The balance between arable and grassland on the cultivated land has been favourable to arable crops.

(4). Sheep farming has been the major activity on the rough grazing land, but improved pastures provide better conditions for sheep rearing and therefore sustain higher numbers of sheep. At certain times, rough grazings were improved to permit farmers to increase their sheep flocks. Also, most cattle rearing took place on the grasslands.

(5). The rates of the increase in farm woodlands have shown the significance of private planting. But no obvious relationships were identified between farm woodlands and other variables due to the fact that only small blocks of farm woodland exist in South-East Scotland. Data from the Forestry Commission's statistics confirm the rapidity of the rise in recent afforestation.

4.5 Summary and Discussion

4.5.1 Summary of the results

The analysis and mapping of agricultural statistics revealed the general characteristics of the land use pattern which supported those found in previous studies (*e.g.* Parry, 1973; McIntosh and Marshall, 1977). From the Lammermuir Hills to the coastal lowlands, land use zones change from sheep farming on rough grazing land to cropping and livestock raising on the higher ground bordering the Hills, and to intensive lowland arable farming. This basic pattern of land use has been maintained for a long time partly as a result of the importance of multiple physical factors and the continuity of agrarian structures, *e.g.*, the preservation of large estates and maintenance of landlord-farmer-tenant relationships. Although the basic pattern of land use has been maintained for a long time, certain trends of changes in land use could be identified from the map series and correlation analysis.

First, the importance of arable farming has been increasing and has expanded towards the uplands. Meanwhile, the acreage of grassland has been decreasing. Second, reflecting the recent widespread afforestation, woodlands on farms have increased through time, as a result of fiscal forestry policies. The total area and the average percentage of land under rough grazing has decreased, which may be due to the conversion to improved pastures and afforestation taking place on rough grazing land. However, the extent of change was not so great and the pattern of its spatial distribution has also been static.

Within arable farming, the increased acreage has been mainly sown to grain. Barley has been most predominant, followed by winter wheat. The total areas of both have increased, but after 1980, the area under barley fell while winter wheat sowing increased greatly. Acreage of oats occupies only a small proportion of tillage and has been decreasing significantly. This can be shown from changes of the area sown both in its absolute value and its relative significance. Other crops which have suffered a decline in acreage are root crops such as potatoes and turnips and swedes. However, oilseed rape is taking an important part in the new farming system. The area devoted to winter oilseed rape has been increasing rapidly during the 1980s.

With respect to the inter-relationships, percentages of total agricultural land under arable crops and farm woodland have been increasing while those for areas of rough grazing and grassland have been decreasing. Therefore, arable farming and rough grazing and grassland tend to have an inverse relationship. Spatially, using the data for the sixty-one parishes within the same year, it was found that significant positive correlations existed between density of sheep and rough grazing, density of sheep and grassland, and density of cattle and grassland whilst inverse relationships were identified between cropland and rough grazing, arable land and density of sheep. The importance of arable farming has been increasing at the expense of grassland while rough grazing has been converted to improved pastures to a certain degree. Sheep rearing was the major activity on rough pastures and higher densities of sheep could be found in those parishes with a high proportion of land under grassland since improved grassland could sustain higher sheep numbers. However, sheep rearing has little significance on arable farms whilst intensive cattle feeding has been widely adopted by arable farmers.

4.5.2 Discussion

The analysis of the agricultural statistics at parish level has enabled the construction of the general characteristics of regional land use through the cartographic representation of the parish summaries and their graphic plotting for temporal monitoring and correlation analysis. It has revealed the patterns of the spatial distribution of land use as well as indicating the trends and the rate of changes in land use. Improved efficiency of the application has been achieved with the help of computer-assisted analysis. However, as pointed out in Chapter 3, there are difficulties in using the agricultural census for land use studies, mainly stemming from the nature of their collection with no reliance upon the accurate locations of the land to which the summaries refer, the consolidation of the returns from individual farms into the parish summaries, and the amalgamations of small parishes leading to the indeterminate location of different land uses within a parish, and above all the lack of suitability of the parish as the basic unit for a detailed land use study. The results can be taken as inaccurate in detail, but reliable in general trend. Still, there is a need on the analysis of the technique applied and the assessment of errors or estimate of confidence. not English Ideally this test of errors or estimate of confidence could have been achieved through comparison between land use activities (*e.g.* woodland or grassland) as reported in the parish summaries and by Landsat image classification for selected parishes. However, this has not been practised because of the incompatibility between different techniques in the analysis and discordances in the definitions of land use categories. At this stage, the ? complementary roles of different techniques mainly exist in a general context. Relationships between different data and methods as well as the needs on analysis of the techniques or errors will be further examined in the following chapters. A detailed study of one parish with integration between remote sensing analysis and parish summaries through GIS will be presented in Chapter 5.

In addition, it is felt that some suggestions can be made in context of a future study to use the detail of the parish summaries to best effect. For instance, a comparison of changes in a few parishes representing situations in the lowlands, uplands respectively would be instructive to extend the analysis of the statistical data with respect to changes in certain key land uses such as rough grazing, cereals, tillage, oilseed rape, farm woodland, grassland, average farm size and labour force. Also, by referring to the detailed categorisation of the summaries, *e.g.*, differentiating beef and diary cattle where possible or examination of the growth of vegetables for human consumption which is important in East Lothian (Coppock, 1976b), the value of the summaries could be more fully exploited. Furthermore, the full potential of the summaries as a source of information for analysing agricultural land use could be demonstrated by application of a multivariate analysis (Robinson, 1981 & 1988). Unfortunately these issues are not pursued in this study due to time limit and because the focal point of this thesis has been put to the analysis of Landsat imagery.

CHAPTER V

MONITORING CHANGES IN LAND USE WITH INTEGRATION OF REMOTE SENSING AND GIS

This chapter reports the results of Landsat image analysis. It demonstrates the utilisation of remote sensing data in mapping regional land use/land cover patterns and detecting its changes. Different procedures and techniques in image processing and assessment of the image classification results are presented. Benefits of the integration between remote sensing and GIS together with the importance in error analysis are also discussed in the chapter.

5.1 Geometric Correction

Geometric corrections of Landsat images (205/21 24 April 1984 of the MSS image and 204/21 14 September 1986 of the TM image), which covered approximately 2500 square kilometres of the study area, were carried out using the GEMSTONE Geometric Correction Module.

Well distributed ground control points (GCPs) were selected from the image and identified on a 1:50 000 Ordnance Survey map of the same area. Eleven GCPs were finally used for the transformation of the TM image while thirteen points were used for the MSS image correction. All those GCPs chosen were easily identifiable, relatively stable features such as road junctions and reservoirs. The reference details of the chosen GCPs for the two images are listed in Appendix 4.

To calculate a transformation, a least squares regression analysis was carried out on the GCPs' values to determine coefficients for the transformation equations that interrelate the geographic and image coordinates. For both the TM and the MSS images, six coefficients were used to fit the x, y pairs with a second order polynomial to achieve an acceptably accurate correction. Details of the defined transformations of the TM and the MSS images, such as EPS (mean-squared errors in pixel sizes of x and y), RMS (root mean-squared) distance error, residual errors in x and y, and a summary of weighted standard errors of the fitted polynomial over the whole input image, are set out in Appendix 4. Among them, RMS error is the distance between the input location of a GCP and the transformed location for the same GCP. It is often used to measure the acceptance of a transformation, *i.e.*, a transformation is accepted when an acceptable RMS error is reached.

The acceptable transformation matrix was saved for the next step of transforming the image data to the required ground coordinate system. The output image configuration was defined by giving the resampling pixel sizes and specifying the top left and bottom right corner coordinates of the output image as map coordinates. In order to compare the results of the two images with different spatial resolutions, the pixel sizes of both images were resampled to 50 m x 50 m. The corrected output area was defined by the British National Grid coordinates shown as in Section 3.3.2.

Finally, the geometric correction on each image band was carried out for the defined area, using the names and parameters supplied. A similar procedure was repeated for each spectral band of data. MSS image bands 4, 5, 7 and TM image bands 3, 4, and 5 were corrected and used for this study. The following formulae can be used to show the relationship between image coordinates and the British National Grid coordinates for the output area delimited by the defined top left and bottom right corner coordinates.

$$E = 314950 + 50X$$

$$N = 686050 - 50Y$$

where X and Y are image coordinates for each pixel, whilst E and N are the British National Grid coordinates representing Eastings and Northings respectively.

Prior to further image analysis, the performance of the geometric correction was examined by randomly sampling some pixels on the corrected image. A comparison of the predicted and actual image or map coordinates was made with help of the above formulae.

The geometric correction of the TM image was demonstrably good and the sampled pixels could be matched very well to those identified on the Ordnance Survey map sheets. The accuracy of fit for the TM image was assessed to within one pixel. However, there were difficulties in visual identification of ground control points on the MSS image due to its coarser spatial resolution (57 m x 79 m). Consequently, this affected the result of its geometric correction. Some parts of the MSS image remained stretched and distorted after the transformation. So did its geometric properties. Especially on the Y axis, it tended to shift two pixels downwards but in no systematic way. Inevitably, this remaining distortion of the MSS image led to difficulties in image comparisons when overlaying the classified results. The final output of the MSS image was registered to the British National Grid to within a two pixel accuracy.

5.2 Training Stage

The importance of selecting training areas prior to classification has been described in Section 3.3.2, as well as the detailed procedures and means involved in obtaining and improving the training data. What has emerged from the training stage is a set of statistics which were generated from the defined training areas. Included in the training statistics are the means and the covariances on every band of data for each defined spectral class. Examples of these saved statistics files can be found in Appendix 5. The process involved in the training stage could be divided into two parts, namely, selection of training fields and manipulation of the training data.

5.2.1 Defining training areas

A combination of aerial photographs, "Farms' Cropping Plan" record data, maps showing road systems and river networks, and maps of land capability for agriculture was involved in this study for extracting training statistics.

Whilst aerial photographic interpretation and the updated Ordnance Survey maps were helpful in identifying woodlands, water surfaces, cultivated land and built-up areas, the record data of the Farms' Division Cropping Plan in the University of Edinburgh's Bush Estate provided a detailed set of ground truth information, especially for identification of certain crops. A copy of some of the Bush Estate record data and maps showing their transformation from aspatial into spatial form is presented in Appendix 6. An example of how these maps were then used to define training areas on the image workstation is shown in Figure 5.1 and Plate 1. Figure 5.1 presents the transformed farm record data for the Bush Estate area in 1986. Areas of grassland, pasture, cereal and root crops can be identified from the figure. Plate 1 is the false colour composite of the Landsat TM image for 14 September 1986. TM band 3 (visible band) was shown in blue, band 4 (near infrared) was in red and band 5 (mid-infrared) was in green. The Bush Estate area as shown in Figure 5.1 was covered in the image. The fine spatial resolution of the TM image enabled individual fields to be discriminated. In comparison with Figure 5.1, Upper Fulford, Neuk and Doo Brae were three pasture fields for cattle grazing in 1986. They were also shown in the TM image with the distinct yellow orange colour. Therefore, those pixels were defined as training area for pasture. Similarly, Beech Grove and Farm House fields were recorded as grassland in their third and fifth year respectively. But the corresponding fields in the image composite showed a bluish tone. This indicated the absence of vigorous vegetation and may suggest the cutting of grass at the time when the image was acquired. However, the spring barley in Mid-Temple field situated in-between Beech Grove and Farm House was still showing its vigorous existence in the image. Thus, this field was defined as the training area for one of the spectral classes of arable land.

Other data such as the updated Ordnance Survey topographic maps were input to the image processing system to assist the image analysis through digital integration. To a large extent, they played a role in improving the interaction between the image analyst and the image data by providing a better knowledge of and easy reference to the study area. The performance of the geometric corrections of images could also be tested by these overlays. Plate 2 shows an example of how these vector data were transformed and overlaid on the imagery data through digital integration. The complexity of land cover in the study area was also demonstrated.

In addition, visual interpolation by the analyst was found both necessary and useful in selecting the training areas to compensate the insufficiency of training pixel numbers and their dispersion, resulting from the insufficient ground truth areas. This visual selection was mainly based upon knowledge of the spectral characteristics of different ground covers and those acquired or deduced from the analysis of known ground covers and their appearance on the images. For example, through the comparison between Figure 5.1 and Plate 1, some crop fields were identified on the image with their unique colour in the three band composite, determined by their spectral signatures. More training fields over areas other than the Bush Estate were then deduced by identifying distinct characteristics of their spectral reflectance in comparison with those for the known ground covers. This was important to give as complete and representative training data as possible, especially when ground truth data for the Lammermuir Hills were not sufficient. This deduction, or subjective visual interpolation, was generally reliable provided that the analyst had sufficient knowledge of the spectral characteristics of different ground covers. Also, it is important to have sufficient known ground covers. As stated by Lillesand and Kiefer (1987:P678), "in many ways, the training effort in supervised classification is both an art and science. It requires close interaction between the image analyst and image data. It also requires substantial reference data and a thorough knowledge of the geographic area to which the data apply."

There are great variations in the appearance of the TM image and the MSS image because of the difference in the seasonal characteristics of the vegetation in the area. The MSS image was taken on 24 April 1984 whereas the TM image was acquired on 14 September 1986. The uniform green colour in the regional vegetation in the April MSS image gave the false colour composite of the image a dominant red tone. The built-up areas in dark-bluish tones with a fine-scattered texture were discriminated from the surrounding rural areas in reddish tones without much difficulty, but grasses and crops could hardly be differentiated due to the similarities in their spectral reflectance. For the TM image, on the other hand, it was a lot easier to identify some crops and grass fields, although there was a confusion between built-up areas and the moorlands. By mid-September, however, many crops had been harvested, leaving the fields with stubble or being ploughed for the next crop, which made them appear in greenish or bluish tones on the image. In contrast, grasses

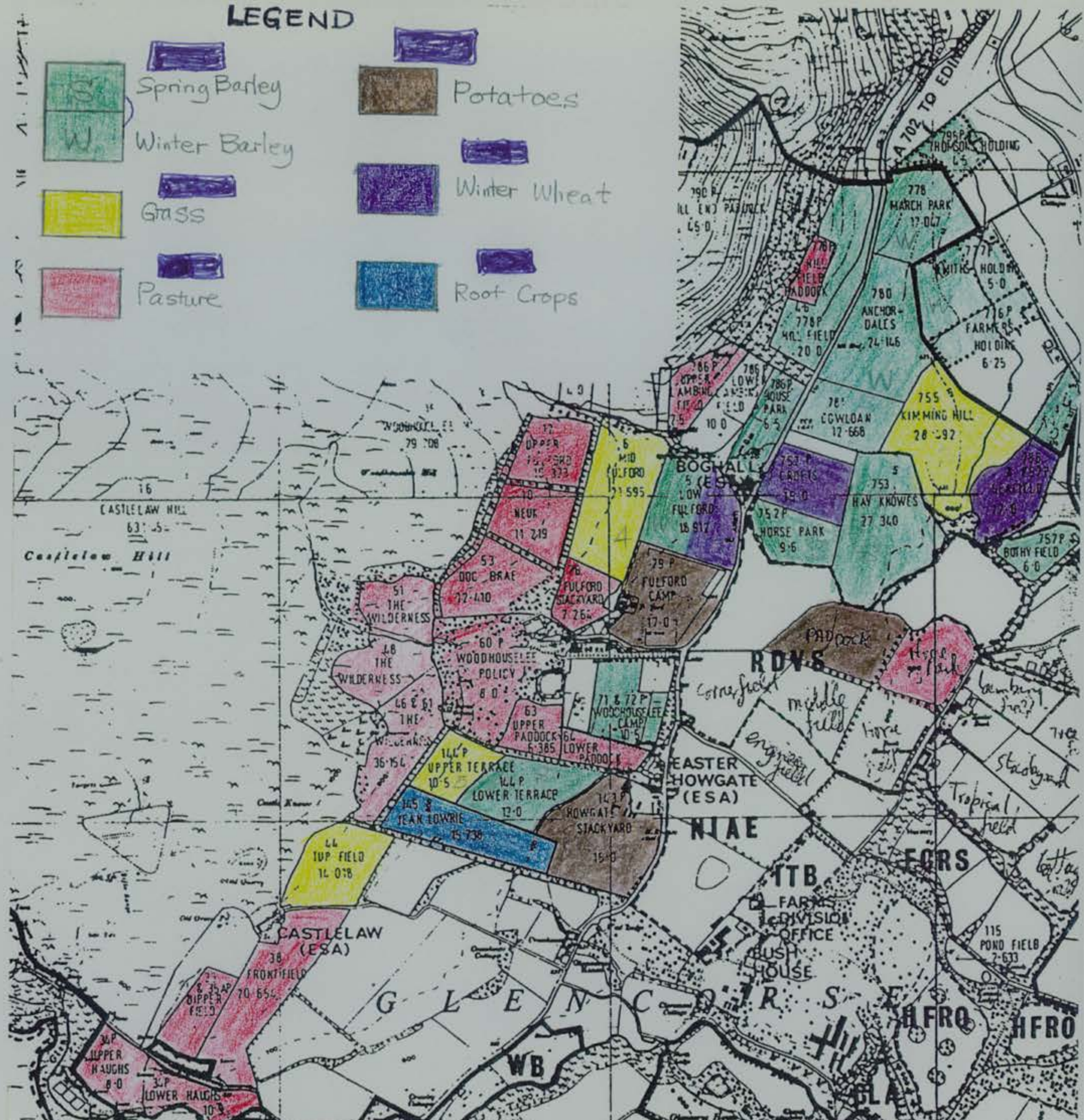


Figure 5.1 Transformed record data for 1986 into spatial form to assist the selection of training areas for the TM image classification (14 September 1986, see Plate 1).

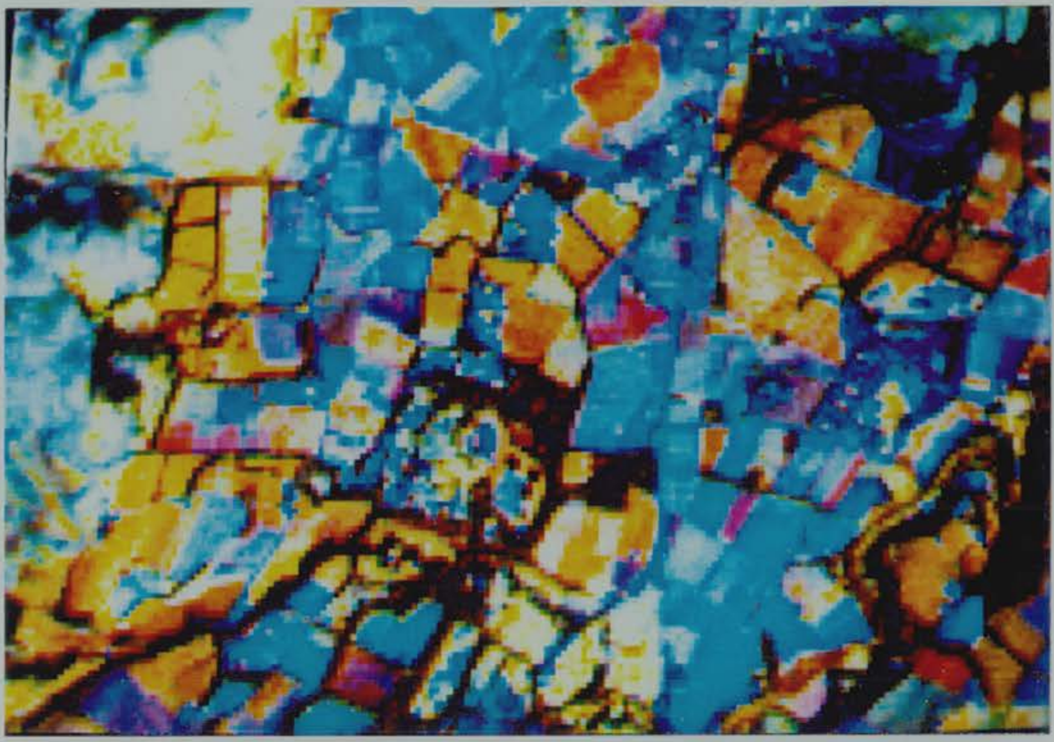


Plate 1 Colour composite of Landsat TM image of Band-3 (blue), Band-4 (red) and Band-5 (green) for the Bush Estate area as shown in Figure 5.1. Notice how well individual fields stand out in comparison with those in Figure 5.1.

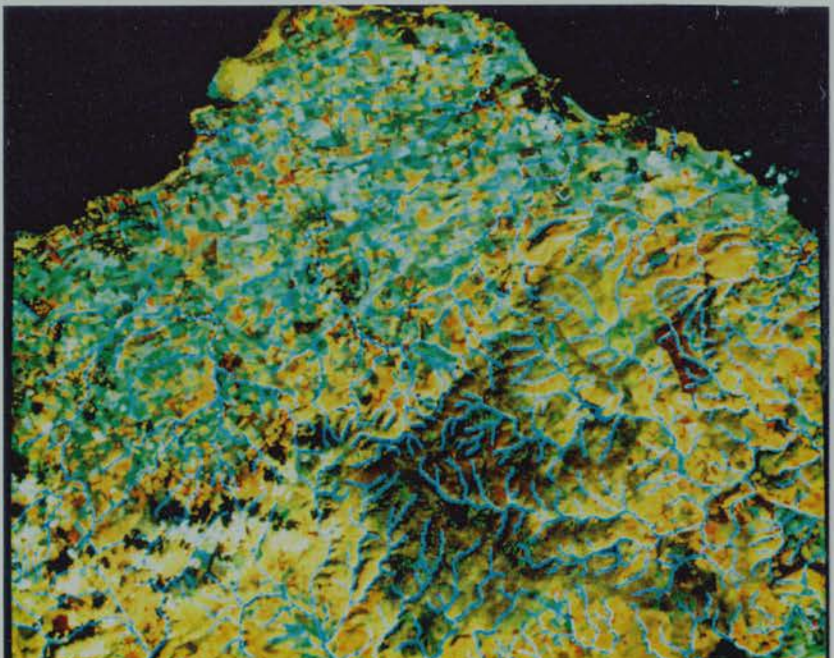


Plate 2 An example of the incorporation of GIS components showing river courses overlaying the TM image (bands 3, 4 and 5) for the Lammermuir Hills and adjacent lowlands in South-East Scotland (14 September 1986).

and permanent pastures often remain vigorous. Their pigments lead to absorption at visible red band and high reflectance at near infrared wavelength. Thus a red or orange colour is often expected in the false colour composite where visible band was displayed in blue, near-infrared band was in red and mid-infrared band in green. Therefore, careful examination of the known areas and proper measures for making subjective decisions were necessarily taken in defining the training areas.

Mixed pixels may form another problem in defining training areas. They are pixels which contain more than one type of land cover. Their existence are often found in the boundary area between one type of land cover and another. The reflectance values of those pixels are thus interfered and represent a combined character of different covers. The pixel-mixing effects were particularly significant for the MSS image analysis due to its coarser spatial resolution (57 m x 79 m). To avoid pixel-mixing effects, more 'pure' pixels were used in training where possible to achieve better statistical representation of each spectral class.

More than one spectral class was defined in order to adequately train on a certain feature. Different types of land use/land cover have different requirements. Some information classes have to be split into a number of classes whilst for others not so many are required. For instance, in this study, one information class was water surface. However, the images under analysis contained more than one water body and they did not have uniform spectral response characteristics over the entire area. Distinct areas of very clear water (*e.g.* reservoirs) and shallow or turbid water (*e.g.* beach, river-side water) could be identified. Therefore, training statistics were required for each spectral class that might be present in the water covered areas. Accordingly, the single information class "water" was represented by two spectral classes: deep clear water and shallow water. Similarly, moorland comprised many spectrally different classes such as dark moors, grey-moors, steep and shadow areas, and burnt moors. All spectral classes constituting each information class had to be represented in the training set statistics of each image in order to carry out a classification. Meanwhile, redundant spectral classes in a classification process must be excluded from a computational point of view (Lillesand and Kiefer, 1987). The larger the number of spectral classes that must be differentiated, the more computations will be required to classify each pixel. To ensure the right number of spectral classes, progressive refinement of training data formed a critical and time-consuming part of building up acceptable statistics for image classification.

5.2.2 Refinement of the training data

The statistics generated from the defined areas were saved as VMS files and could be edited and retrieved for further use. In the process of training set refinement, the analyst revised the statistical descriptions of the category types through merger, deletion and addition to form the 'final' set of statistics used in classification.

For instance, to reduce the confusion between built-up areas and moorlands in the classification of the TM image, segmentation of the image was applied in carrying out the image classification. The whole image was delineated into an intensive moorland area and the rest of the area without rough moors, according to the ground features and the characteristics of the image scene. Then each segment was classified separately using a region-based maximum likelihood classifier with different sets of statistics. Twenty-five spectral classes, which were enough to pick up most spectrally separated features, were involved in the classification of the moorland areas. The detailed statistics for the classification are shown in file "ficlas.sta" in Appendix 5. For the classification in the remainder of the image, three more training areas were defined and added to the twenty-five areas predefined and then the statistics were saved in file "seclas.sta" with twenty-eight areas in total (see Appendix 5). To exclude errors of built-up areas misclassified as moorland, the statistics file was further edited to "thclas.sta" with those areas defined as moorlands being removed (see Appendix 5). The statistics were then ready to be used for the TM image classification on the areas without rough moors.

Similar procedures were applied in assembling the training data for the classification of the MSS image. The farm record data for 1984 were transformed into their spatial form for selection of training areas for the April 1984 MSS image. The coarser spatial resolution of the MSS image did require greater effort in chosing the training fields. However, most areas were identified with help of the ground truth data and the texture and size of the image. The statistics were then compiled into three sets. One was for the classification of the areas where there were no moorlands. Another was used for the intensive moorland areas without arable farming or urban use. Last, the other set of statistics was applied to the fringe area of moorland and arable land. This information is detailed in Appendix 5.

In sum, great effort has been put to define training areas by making full use of the available data and to account for the complexity of land cover in the study area. Whilst visual interpolation or deduction of the training areas was subject to criticism, it should be appreciated as a necessary step when ground truth data were not available over the entire study area. Active involvement of the image analyst ensured a close interaction with the image data as well as the progressive refinement of the training statistics. This formed a basis for the success of image classifications.

5.3 Classification Results

Using the saved training sets of statistics, pixels of unidentified cover type were categorised into their appropriate classes using a maximum likelihood classifier. Assuming that the training sample of each class could be represented by a multivariate normal probability distribution, the classifier mapped probability in the feature space for all the classes and assigned each pixel to the class for which it had the highest probability. A pre-set cut-off probability level was specified for each class prior to classification. A high probability level restricted the class while a low probability level allowed the class to expand. Where the cut-off limit defined the boundaries of a class in the case of no overlap, the areas beyond this were assigned as unclassified, *i.e.*, the pixel would be labelled "unknown" if the probability values were all below a threshold set by the analyst. The classification was then performed on the defined part of the image.

As explained in Section 5.2, the 'final' set of statistics for the TM data were actually compiled into two groups. Each was used in different parts of the image. Then the classified results of separate parts of the image were copied into a whole image and the pixel location on each subscene remained unchanged. This reunited image after classification was then treated as a new image showing the final classification results. The

GEMSTONE-35 stored the maximum likelihood results as a combination of the class and probability. A rejection level of 0.2 per cent was chosen. The final classified image mainly covered the Lammermuir Hills area delimited by the National Grid coordinates as follows:

	Eastings	Northings
Top Left	335000	686000
Bottom Right	380000	648000

For the TM image, spectral bands 3, 4 and 5 were chosen for the maximum likelihood classification. Although they were the only TM bands available, this 'limitation' of three data bands can be justified because they provide potentially all the information needed in the analysis. Also, reduction of the number of Thematic Mapper channels was considered necessary for a maximum likelihood classification in order to ensure the efficiency of Maximum Likelihood Classifiers as well as to save cost in data processing (Belward *et al*, 1990). With the cut-off probability level being set to 0.2 per cent, the proportion of unclassified pixels for the whole classified area was 7.48 per cent. This is acceptable considering that clouds/shadows were finally included in the unclassified category. The detailed figures and plates showing the segmentation of the image and the classifications are presented in Appendix 7. It is visually clear that the segmentation of the image into subscenes for classification helped to reduce certain obvious errors, *e.g.*, pixels classified as built-up areas on the moors and built-up areas classified as moors can be readily excluded.

Similar procedures were applied to the MSS spectral bands 4, 5 and 7. Using the saved statistics for the MSS data, the unclassified pixels took 8.00 per cent of the final classified area.

The images containing classification results were enhanced by applying a majority mode filter to exclude isolated pixels in a uniform field and to reduce the number of unclassified pixels. This process was based upon the assumption that contiguous, homogeneous pixels usually indicate a spatial pattern within the data. For this study, a 7 x 7 post classification majority mode filter was used with help of the GEMSTONE filtering modules. The percentage of pixels remaining unclassified for the TM image was reduced from 7.48 per cent to 4.73 per cent after the filtering. Similarly, the proportion of unclassified pixels for the MSS image was reduced from 8.00 per cent to 3.81 per cent by applying a post-classification mode filter.

The classified image files with information on spectral classes were further recoded into new groups representing feature classes using the RECODEIMAGE modules of GEMSTONE-35 to ARC/INFO interface. This produced rapid combination of classes prior to transference to ARC/INFO or for redisplay on the GEMSTONE workstation. By defining the same set of information classes for the two images of different dates, this helped to meet the need for comparison of classification results. For the TM image, the number of classes was reduced from 28 to 9 after the recoding, *viz.*, water surface, grassland, pastures, arable land, moorland, forest land, built-up area, clouds/shadows and unclassified area. They represent the general categories of land use/land cover for this study.

In this example, water surfaces include mainly the sea and reservoirs. The classifier generally failed to identify rivers or other narrow water surfaces. This was partly due to the comparably coarse resolution of the image and was partly attributed to the existence of the common tree planting along river sides. The post-classification filtering of the image only made this more difficult. Grasslands are usually managed and sown, with mowing for silage cut from time to time. In this study, temporary grassland, meadow grass areas and golf courses or links were also defined as grassland due to the difficulties in spectral differentiation. Pastures are mainly permanent grasslands. They are usually intensively grown grasses, with some management but without being sown for at least five years. Arable land includes areas under various crops and fallow. Moorlands here mean the unmanaged rough pastures. They are mainly used for rough grazing or are of little productive agricultural use. Forest land consists of coniferous, deciduous and mixed woodlands. Urban and built-up areas chiefly comprise residential, industrial, commercial and transportation areas.

The same definitions of land use/land cover categories were applied for the MSS image except for the absence of a clouds/shadows category.

5.4 Accuracy Assessments of the Image Classifications

Accuracy assessment of the classification performance as a whole was made by manual random sampling of individual pixels for each of the following feature classes: water surface, grassland, pasture, arable land, moorland, forest land and built-up areas. The sample size for each class was determined by its weight in the whole image and the preliminary estimate for the expected accuracy of each category. For instance, the expected accuracy of water identification was high by visual judgement, and the sea and reservoirs are clearly shown on both the map sheets and the image scene. Therefore the sample size for the feature class of water surface was rather small, but for the feature class of arable land, many more points were chosen to be checked with the ground data. This was because, firstly, the definition of arable land was much wider than that of water: it included all the fields under crops and fallow. Secondly, the identification of crop lands from the image analysis was very complicated and many more spectral classes were defined for this category. There was also difficulty in differentiating crops and grasses on the image. All these problems added to the uncertainty of the classification performance and thus led to a large sample size for arable land. The inclusive and exclusive classification errors were then examined by checking with the updated Ordnance Survey map sheets (1983 and 1986). The 1:25 000 Ordnance Survey map sheets offer a set of detailed information on some land use/land cover features. This examination was also supplemented by field checking and *a priori* knowledge of the area. This knowledge mainly came from the analysis of aerial photographs and of agricultural statistics. As a result, Table 5.1 was produced to show numbers of sampled pixels in actual and classified land use/land cover categories for the Landsat TM data and Table 5.2 presents those for the MSS image.

According to van Genderen (1977), this type of contingency table shows the following aspects:

1). The frequency that any one land use/land cover type (on the ground) is erroneously attributed to another class, such as those values in row F1 of each table. For both image classifications, delineation of water surfaces gave the best performance while grassland seemed most frequently missed out.

Table 5.1 Numbers of sampled pixels of the TM image in actual and classified land use/land cover categories

Land Use (on the ground)

Land Use (image classification)

	water	grass	pasture	arable	moorland	forest	built-up	total	F2
water	26							26	0
grass		37	2	8		1		48	11/48
pasture		4	45		1	2		52	7/52
arable		5		108			6	119	11/119
moorland			3		29	4		36	7/36
forest						51		51	0
built-up				5	1		25	31	6/31
total	26	46	50	121	31	58	31	363	
F1	0	9/46	5/50	13/121	2/31	7/58	6/31		42/363

Table 5.2 Numbers of sampled pixels of the MSS image in actual and classified land use/land cover categories

Land Use (on the ground)

Land Use (image classification)

	water	grass	pasture	arable	moorland	forest	built-up	total	F2
water	26						1	27	1/27
grass		33	9	6				48	15/48
pasture		2	59	6	1			68	9/68
arable		7	5	74	3		2	91	17/91
moorland			1		43	9	1	54	11/54
forest		5	1	1		51		58	7/58
built-up				7			23	30	7/30
total	26	47	75	94	47	60	27	376	
F1	0	14/47	16/75	20/94	4/47	9/60	4/27		67/376

2). The frequency that the wrong land use/land cover class (as observed on the ground) is erroneously included in any one class, *e.g.*, those in column F2 of the tables. Again, water surface and forestry had the least commission errors.

3). The proportion of all sampled pixels which are misclassified. In this study, 42/363 (11.6%) of all attributions were incorrect for the TM image analysis and 67/376 (17.8%) of those for the MSS image classification.

4). The determination of whether the errors are random or subject to persistent bias. In general, the mistakes in the samplings were random. Therefore the overall proportions were approximately correct. However, there was a tendency to mis-attribute grassland (on the ground) to arable land, *e.g.*, 5/46 (10.9%) for the TM image and 7/47 (14.9%) for the MSS image.

An overall measurement of classification accuracy was made by expressing the total of diagonal elements of the contingency table as a proportion of the total entries for the whole table, where the diagonal entries were the correctly classified pixels and off-diagonal entries were incorrectly classified (Story and Congalton, 1986). Thus the overall classification accuracy for the TM image was assessed as 88 per cent and that for the MSS image analysis as 82 per cent. These figures will be carried forward into the change detection exercises in Section 5.5. As pointed out by Singh (1989), the change map product of two Landsat classifications is likely to exhibit accuracies similar to the product of multiplying the accuracies of each individual classification. In general, the classification performance for both images was satisfactory, although certain classes such as grassland failed to meet the requirements proposed by Anderson *et al* (1976) in the USGS classification system, that the minimum level of interpretation accuracy in identifying land use/land cover categories from remote sensing data should be at least 85 per cent. But this is not a fixed rule. Also, the difference between the landscapes of the two countries and the diversity of land cover/land use must not be ignored. The largely dissected landforms in Scotland and the subtle change in land use within a relatively small area added to the difficulties in image classification. Therefore, it is virtually impossible to achieve this level of accuracy for all the classes in this study.

Whilst taking the classification results with acceptable levels of accuracy, it is important to recognize that they are subject to where the sample points were chosen. For example, if most sampled pixels happened to be in the boundary areas between different classes, reduced accuracies could be expected because of the existent errors in the image registration and the pixel shifting effects. Analysis and discussion of the classification performance are further considered in Chapter 6.

5.5 Comparison of Classification Results and Change Detection Exercises

The presentation and comparison of the classification results can be achieved by using either the GEMSTONE image processing system or the ARC/INFO GIS, as explained in the following two subsections.

5.5.1 Detection of changes using GEMSTONE image processing system

Once the image classification and recoding have been completed, the results can be compared readily for detecting changes in any type of land use/land cover for a defined area. The ground area (*i.e.* quantitative statistics) for each category can also be estimated. The following example shows the procedures for this using GEMSTONE Modules.

An example: Detection of changes in forestry

<u>Making masks from images</u>

A mask in this case is a special kind of image whose pixels only have values of 0 or 255. It is used to show those parts of a region conforming to a particular type, such as forestry. A pixel value of 255 in the mask indicates an occurrence of the given type in the corresponding cell while a value of 0 indicates its absence. A mask can be created by applying a density slice to the recoded image of classification so that the areas of the specified type (forestry in this case) are displayed in white and all other areas in black. The GEMSTONE Copy module is then instructed to store the displayed image such that white pixels are copied as 255 and black pixels as 0. In this way, two masks were created to show the forestry distribution in both images. Assume Mask-1 shows areas of forestry in 1984 and Mask-2 shows those in 1986.

Using Arithmetic programmes

The symmetric difference of the two masks, which shows those areas on either mask that are not on the other, can be found by using the XOR (exclusive-or) logical operation available in the GEMSTONE Arithmetic module. For instance:

store 1: - [mask-1] XOR [mask-2]

Thus store 1 shows the areas of change in forestry between 1984 and 1986. Then the areas deforested since 1984 are given by

[mask-1] AND store 1

whilst the areas afforested since 1984 by

[mask-2] AND store 1.

The AND function produces the intersection of two masks, *i.e.*, the pixels which have values of 255 in both.

Deriving the statistics

Apart from showing the spatial distribution of changes in forestry, quantitative statistics can be obtained. The pixel numbers within each mask can be counted using the density-slice module, taking all the pixels with a value of 255 as one slice. Then the corresponding ground area can be estimated by multiplying the number of pixels in the slice by the area of a single cell which in this case is 50 x 50 square metres. Therefore, assuming the accuracy for woodland classification was 100 per cent and the two images were perfectly registered to the British National Grid, the woodland areas in 1984 and 1986, and the afforestation and deforestation which took place during the period could be worked out, as shown in Table 5.3 for the image area delimited by the following British National Grid coordinates:

	Eastings	Northings
Top left	335 000	685 000
Bottom right	380 000	650 000

Table 5.3 Changes in forestry 1984-1986

Total=631601	Pixel Number	Percentage	Area (ha)
Forestry-84	20891	3.31	5223
Forestry-86	23286	3.69	5822
Deforestation	8910	1.41	2228
Afforestation	11305	1.79	2826

However, strictly speaking, this method of area estimates should only be used for areas where terrain is flat. Also, the land cover classification has been generated from a single date of Landsat data and the two images were taken during different seasons of different years. Thus it can produce a number of erroneous change indications since an error in the image classification on either date gives a false indication of change. As mentioned before, the values in Table 5.3 would only be correct if the accuracy for woodland classification were 100 per cent and the two classifications were perfectly comparable. Otherwise, they must be modified where possible to be near to the reality, taking into account errors in each image classification and the possible errors resulted from comparison of two images. In Table 5.2, the sampled pixels for the MSS image classification show that 7 out of 58 pixels were erroneously included as the classified forest and 9 pixels were erroneously attributed to other classes corresponding to the 51 pixels classified as woodland. Therefore, the total area of forestry in 1984 should be modified from 5223 hectares to 5403 hectares (5223 x 60/58) taking into account the commission and omission errors in the woodland classification. Similarly, using the statistical figures in Table 5.1, the total woodland area for 1986 should be adjusted to 6621 hectares (5822 x

58/51) where errors were purely attributed to omission. However, it should be noted that these adjustments were only made based upon the sampled statistics of commission and omission rates without measuring the errors' spatial dependence. If changes in forestry were to be measured singly by these statistical figures, changes in woodland and trees between 1984 and 1986 would be the afforestation area of 1218 hectares (6621 - 5403) for the study area. However, the afforestation and deforestation areas as shown in Table 5.3 were a result of comparison between two classifications being dependent upon the distributions of woodlands in either image and reflecting the internal changes within woodland plantations. Therefore, the amount of afforestation and deforestation calculated in this way should not simply be compared with statistics obtained usually only as an overall figure without reporting any internal changes. Still these figures in Table 5.3 need to be modified and possible errors should be considered.

As discussed in Section 5.4, the change map product of two Landsat image classifications probably exhibits accuracies similar to the product of multiplying the accuracies of each individual classification. Thus the overall accuracy for the change product is likely to be 72% (82% x 88%). With regard to changes in forestry, this may get even more complicated because omission and commission errors have to be considered separately and adjusted accordingly. Using Table 5.2 and Table 5.3, the 5223 hectares of classified forestry for 1984 might have 630 hectares (5223 x 7/58) erroneously included and 810 hectares ((5223-630) x 9/51) might have been erroneously omitted. Similarly, using Table 5.1 and Table 5.3, the 5822 hectares of classified forestry might have 799 hectares (5822 x 7/51) omitted and erroneously attributed to other classes. When carrying out the change detection exercise, it is likely that these errors would directly attribute to more errors in the change product. For example, the omission error (810 ha) in the 1984 image classification and the commission error (0 ha) in the 1986 image classification would lead to over-estimates of afforestation during this period whilst the commission error (630 ha) in the 1984 image and omission error (799 ha) of 1986 image classification might result in under-estimates of afforestation. Thus the afforestation figure could be adjusted to 3445 hectares (2826 - 810 + 630 + 799). Similarly, the deforestation area could be modified to 1609 ha (2228 - 630 - 799 + 810) where the commission error in the 1984 image classification and the omission error in the 1986 image classification could lead to over-estimates whilst omission error in the 1984 and commission error in the 1986 would contribute to under-estimates. Again, these adjustments could only be practised in terms of their statistical omission and commission rates.

The problem of the inherent errors in performing the change detection by comparison between classifications of the two images was exacerbated by the possible boundary errors in the two images. As discussed in Section 5.1, the remaining distortion of the geometrically corrected MSS image leads to errors in overlaying the classified images. This shifting of images precludes the accurate registration of images and thus leads to the changes being spatially correlated when carrying out the change detection exercise. Unfortunately these errors could not be adjusted easily as the boundary shifting effects were not taking place in a systematic way over the whole study area. Also, the limitations of the approach may be partly attributed to the difficulty in producing comparable classifications from one date to another. Further error analysis and a detailed study of one parish can be referred to in the following sub-section and in Chapter 6.

5.5.2 Comparison of results on ARC/INFO GIS with study on a parish

After the accuracy assessments, the classification results were transferred to ARC/INFO using GEMSVF and GRIDPOLY modules of GEMSTONE-35 to ARC/INFO interface, which has been developed in the Department of Geography, University of Edinburgh. Some functions of ARC/INFO GIS on coverage manipulations then helped answer questions automatically concerning where the change was; what the change was, *i.e.*, from which to which; how the land use/land cover has been changed and to what extent the change has occurred.

The classification results were presented in ARC/INFO using a high quality plotter. Map 5.1 and Map 5.2 show the classification results in this study for the MSS image of April 1984 and the TM image of September 1986 respectively. They offer several advantages over the hard copy of the imagery data. First, they are registered to the selected ground coordinate system (British National Grid) so that they work as the new thematic overlays in the GIS. Then the maps were scaled and designed in a flexible way without the need for photogrammetric skills or expensive printing. These advantageous characteristics are demonstrated in Maps 5.1-5.7.

Apart from automated high quality plotting, ARC/INFO GIS enables the attribute and locational components to be inter-related. The UNION function creates new polygons by overlaying polygons from two coverages and associating their attributes with each new polygon. It combines two polygon coverages while keeping all the features from both of them. Items from the input and the union coverages are merged in the output coverage. Therefore, again taking woodland as an example, information on afforestation or deforestation, or the areas of afforestation which took place on arable land or rough grazing, *etc.* could be easily obtained by selecting certain features (*e.g.* Map 5.5) in the new overlay coverage. Examples of the command files for selection of features and production of plot files can be found in Appendix 8. Both the spatial distribution and the attribute data were shown in the outputs subsequently. Other spatially related coverages, such as the coverage showing parish boundaries, were readily incorporated (see Maps 5.3-5.5). Map 5.3 shows the areas of afforestation for the whole study area from 1984 to 1986. The total area of afforestation is 2826 hectares. Map 5.4 presents those of deforestation with a total area of 2228 hectares. Map 5.5 demonstrates changes in woodland areas between 1984 and 1986. As for the accuracies of these change products, the same adjustments should apply as those referred to in the last sub-section. Many questions can then be answered from these maps. For instance, those localities under shade 1 in Map 5.5 indicate areas changing from woodland to grassland with a total acreage of 90 hectares (0.9 km^2) for the whole test location. As pointed out in Section 5.5.1, these figures may not be realistically comparable because of the existent boundary errors and the errors inherited from classifications of the two images. Therefore, it is likely that some questions in relation to the changes of land use/land cover remain unanswered. However, as far as the method is concerned, it has demonstrated the utility of the post-classification comparison method for detection of changes of land cover/land use, provided that accurate and comparable classification results are produced. The integration between the image processing system and ARC/INFO GIS enhances its potential and places the detection of changes in land use/land cover in a wider context. One of the incomparable advantages of detection of changes of land use/land cover through comparison of classifications of different images is that it can relate the amount of changes to their spatial locations as well as reveal the internal variations over a time period. This information is often not available from the agricultural statistics or other conventional data. To further demonstrate the benefits of the integration between remote sensing and GIS, a detailed study of a selected parish was undertaken.

With the integration between remote sensing and GIS, a detailed study for any selected parish can be performed without difficulty. Results of the spatial location and the aspatial attributes of certain land uses can be compared with the recorded parish statistics. For example, by building the Polygon Attribute Table (PAT) within ARC/INFO for the coverage of parish boundaries, each parish with its identification code is related to features in the UNION coverage where all the features from the two classification images were stored. Therefore the spatial distribution and the related attribute data can be established for any selected parish. These data can then be compared with the parish statistics as retrieved from the University of Edinburgh Data Library. In this case, Innerwick with a parish code of 351 (parish codes as used in the Data Library are presented in Appendix 1) was selected for study of changes in forestry. The OVERLAY coverage which is the output of UNION of two classification coverages was clipped to the required area for Innerwick parish. Map 5.6 shows the distribution of forestry in Innerwick for 1984 and 1986. There were 473 hectares of woodland in 1984 and 548 hectares in 1986. Using the same method as in the last sub-section for adjustments, these figures could be modified to 489 hectares (473 x 60/58) for 1984 and 623 hectares (548 x 58/51) for 1986. According to the parish summaries, there were 80.4 hectares of agricultural land in Innerwick used for farm woodland in 1984 and 291.1 hectares in 1986. Thus, from 1984 to 1986 land used for farm woodland has increased by 210.7 hectares. However, this does not reflect any work done by the Forestry Commission as the parish summaries only refer to farm forestry. Unfortunately no information is available on the plantation of woodland and trees by the Forestry Commission at parish level. However, the performance of image identification of woodland at Innerwick may be checked out by examining the updated Ordnance Survey map. For example, two big blocks of forestry have been identified in the Ordnance Survey

1:50 000 map (sheet 67) in both the 1983 and 1989 editions. One is High Wood and the other is the block of woodland cut through by Monynut Water as shown in the Xerox copy of the Ordnance Survey map in the following page. These two forestry areas have also been identified correctly on the Landsat images as shown in Map 5.6 although they may not fall exactly into the Ordnance Survey mapped areas. It could be argued that analysis of Landsat images provides more updated information than the Ordnance Survey maps. Although the new map series of 1:50 000 Ordnance Survey map was sometimes taken as the most up-to-date national representation of woodland available, revision by Ordnance Survey does not necessarily take place over a whole map sheet at one time and even the most recently published editions are never completely up-to-date either for this reason or because of the lapse of time between survey and publication (Locke, 1987). Therefore, categories such as cleared, disforested or extra woodland exist in the Census of Woodlands and Trees carried out by the Forestry Commission. Similarly, areas where different land use/land cover classes were found between Ordnance Survey map and the imagery analysis should be checked by ground truthing. For example, as shown in Plate 3, the middle of High Wood block appeared in cyan in the false colour composite of TM bands 3 (blue), 4 (red), and 5 (green). Thus, the reflectance in the visible and mid-infrared bands are higher than the near infrared band. The *a priori* knowledge of the spectral characteristics indicates the existence of bare ground or little vegetation. Therefore, it is likely that they were woodland area as marked on the 1:50 000 Ordnance Survey map, but at the time of the images were taken, they were cleared of trees and had not been converted to another land use. The ground truthing in 1988 could indirectly confirm this assumption, though two years had lapsed after the TM image was acquired. In 1988, the area was covered by unmanaged grasses. Therefore, in this case, the Landsat image classification gives more information on the status of woodlands and trees than the Ordnance Survey map.

Also, in respect to the change detection, the information from the parish summaries is limited to the changes in the total amount of land used for woodland in the parish without any information on the actual locations or the internal changes for the farm woodland. Map 5.7 shows the distribution of the afforestation and the deforestation between 1984 and 1986 in the parish together with the amount of changes taken place. Again, these figures could

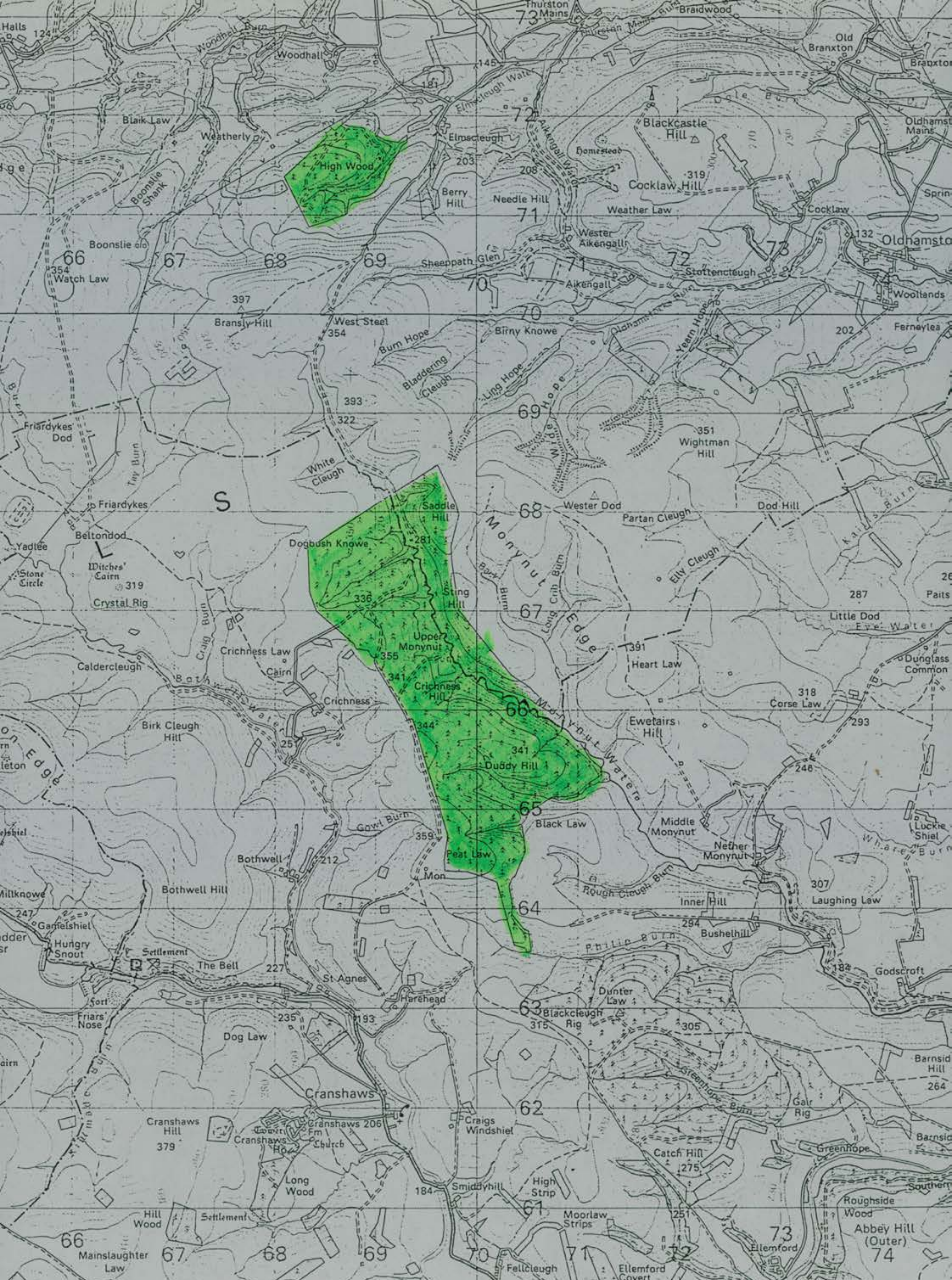

High Wood
Woodhall
Weatherly
Blaik Law
Boonslie Shank
Boonslie
Watch Law
Elmscleugh
Berry Hill
Needle Hill
Blackcastle Hill
Cocklaw Hill
Weather Law
Cocklaw
Oldhamstocks
Old Branxton
Braidwood
Thurston Mains
Wester Aikengall
Aikengall
Stottencleugh
Woollands
Ferneylea
Sheeppath Glen
Bransly Hill
West Steel
Burn Hope
Bladdering Cleugh
Birny Knowe
Ling Hope
Wightman Hill
Friardykes Dod
Friardykes
White Cleugh
Saddle Hill
Wester Dod
Partan Cleugh
Dod Hill
Beltondod
Yadlee
Witches' Cairn
Stone Circle
Crystal Rig
Dogbush Knowe
Sting Hill
Monynut Edge
Elly Cleugh
Little Dod
Eye Water
Upper Monynut
Crichness Law
Caldercleugh
Cairn
Heart Law
Dunglass Common
Crichness Hill
Crichness
Corse Law
Ewetairs Hill
Birk Cleugh Hill
Duddy Hill
Monynut Water
Black Law
Middle Monynut
Nether Monynut
Gowl Burn
Bothwell
Peat Law
Luckie Shiel
Bothwell Hill
Rough Cleugh Burn
Inner Hill
Laughing Law
Bushelhill
Philip Burn
Godscroft
Gamelshiel
Hungry Snout
Settlement
The Bell
St Agnes
Harehead
Dunter Law
Blackcleugh Rig
Friars' Nose
Dog Law
Cranshaws
Cranshaws Hill
Cranshaws Ho
Church
Craigs Windshiel
Greenhope Burn
Gair Rig
Barnside Hill
Catch Hill
Greenhope
Long Wood
Smiddyhill
High Strip
Moorlaw Strips
Roughside Wood
Abbey Hill (Outer)
Hill Wood
Mainslaughter Law
Fellcleugh
Ellemford Covert
Ellemford
Ellemford Bridge

Plate 3 Colour composite of TM band 3 (blue), band 4 (red) and band 5 (green) showing High Wood and Monynut water at Innerwick area (14 September 1986).

be adjusted by considering the omission and commission error rates. As discussed in Section 5.5.1, the classified 473 hectares of woodland for Innerwick in 1984 might have 57 hectares (473 x 7/58) being erroneously included and have 73 hectares ((473-57) x 9/51) erroneously omitted. Similarly, the 548 hectares of classified woodland in 1986 might have 75 hectares (548 x 7/51) omitted and erroneously attributed to other classes. Therefore, the afforestation for Innerwick should be adjusted from 220 hectares to 279 hectares (220 - 73 + 57 +75) and the deforestation area of 145 hectares could be modified to 86 hectares (145 - 57 - 75 + 73). Thus the difference between the statistics of afforestation and deforestation indicates an overall 193 hectares (279 - 86) increase in woodland. This is close to the 210.7 hectares obtained from the parish summaries. Again, the compatibility of different data sources must be stressed to achieve realistic output and to complement findings of each other.

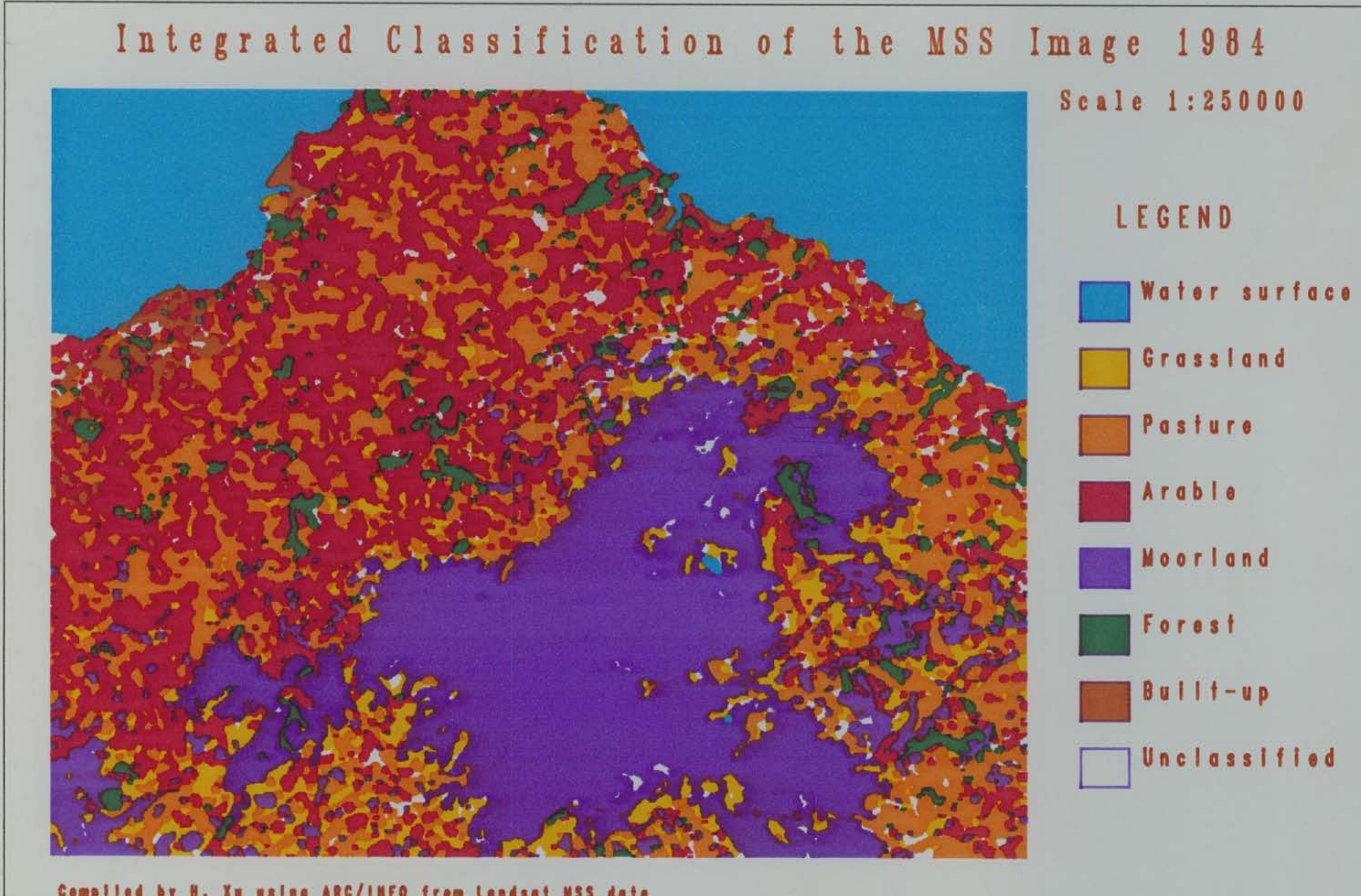
In addition, by examining the locations of these changes in Map 5.7, the spatial correlation of changes could be better understood. As pointed out at the end of Section 5.1, some parts of the MSS image remained distorted after the geometric transformation, especially in the Y axis, where there was a tendency to shift two pixels southwards but in no systematic way. Thus, it is possible to expect a trend that for changes taking place near the boundary areas of a forestry block, afforestation would mainly appear in the northern parts whilst deforestation would be expected in the southern boundary areas. This has been demonstrated in both Map 5.5 and Map 5.7. Obviously these changes were caused by the shifting effects of the MSS image registration. As a result, some spatial correlations were established between changes. The reliability and applicability of the product for change detection were thus limited. Unfortunately the error of this shifting effect can not be assessed easily since it occurs in no systematic way. Caution is exercised here and more attention should be given in future work.

5.6 Summary

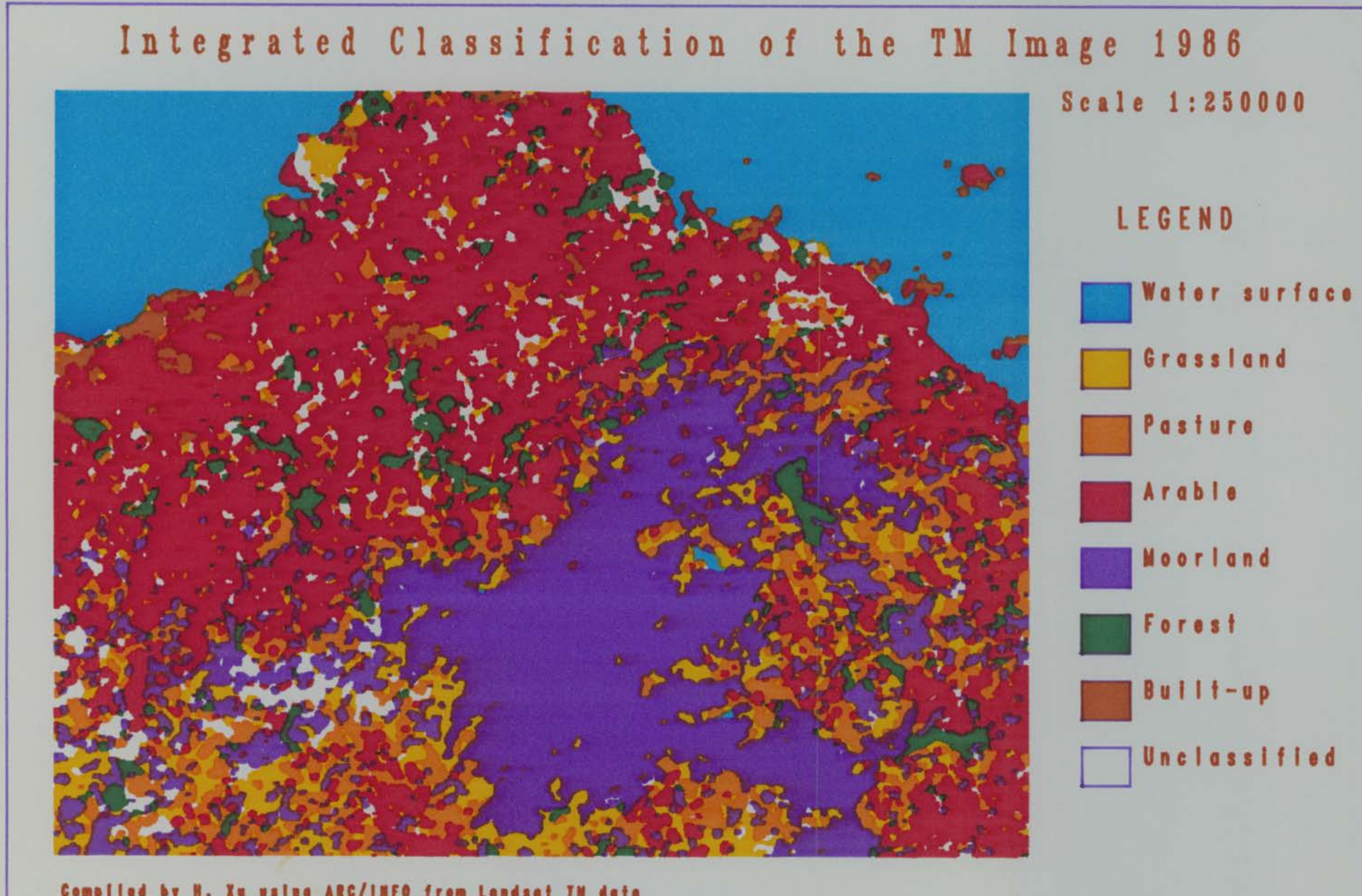
This chapter examined the practical problems of integrating information derived from image analysis with other data using GIS technology with the primary objective of monitoring changes in land use/land cover. Results with adequate overall accuracies of integrated classifications for both the MSS and TM images were achieved using the statistics generated from progressive refinements of training data and further enhancement by applying a post-classification majority-mode filter. Whilst integrated image classification offers advantages over single resource identification, difficulties were encountered with the classification of single date images. There is also room for improvement in the efficiency of achieving results of the same order when more advanced facility with increased computing capacity is available.

The presentation and comparison of the classification results can be accomplished by using either the GEMSTONE image processing system or the ARC/INFO GIS. However, the use of ARC/INFO GIS allows the incorporation of other data as well as the systematic handling of different data-sets. Therefore the detailed study of selected parishes and comparison between Landsat imagery analysis and the parish summaries can be carried out. The interface between remote sensing and GIS also shows its effectiveness by allowing the image classifications and comparisons to be demonstrated and justified in a practical way.

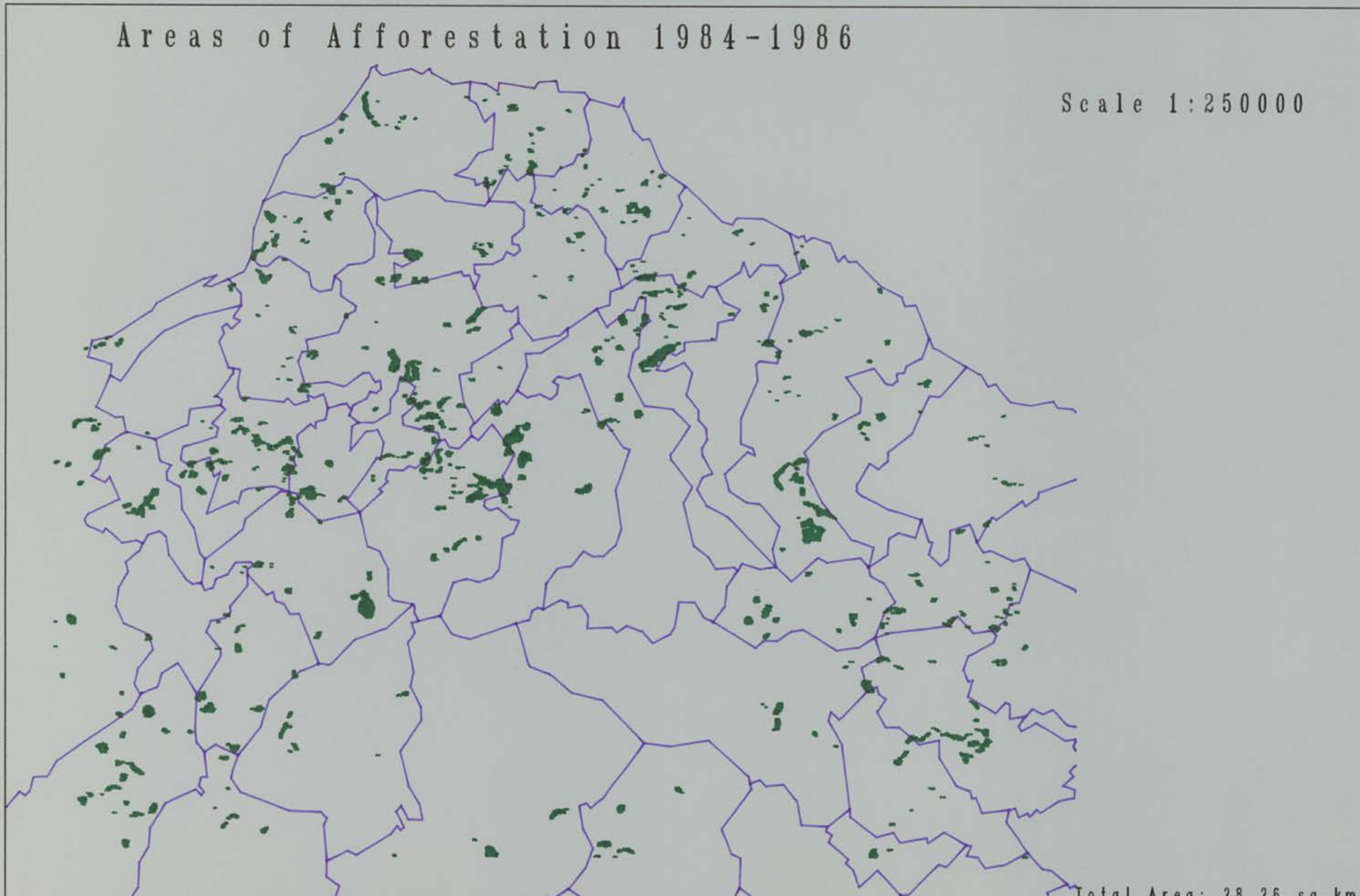
However, caution must be given in detecting changes through comparison of classification results for different dates. Spatial correlation revealed in the change products resulted from boundary errors and error propagation of single date image classifications should all be taken into account when using the method for studies of changes in land use/land cover. The relationship between the imagery analysis and statistical data together with the problems and limitations identified in the study are further addressed in Chapter 6.



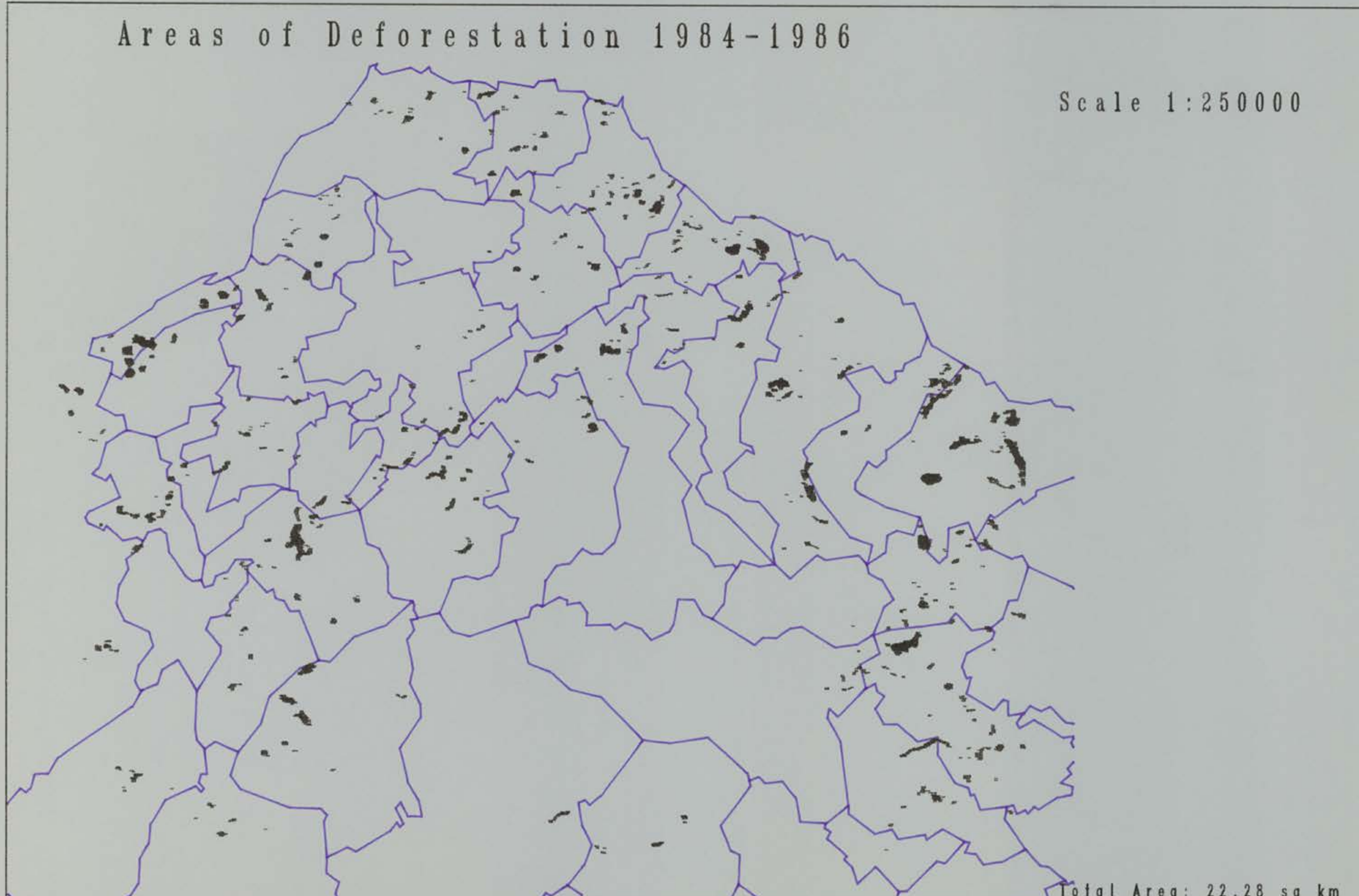
Map 5.1 Automated plotting of the MSS image classification (24 April 1984)



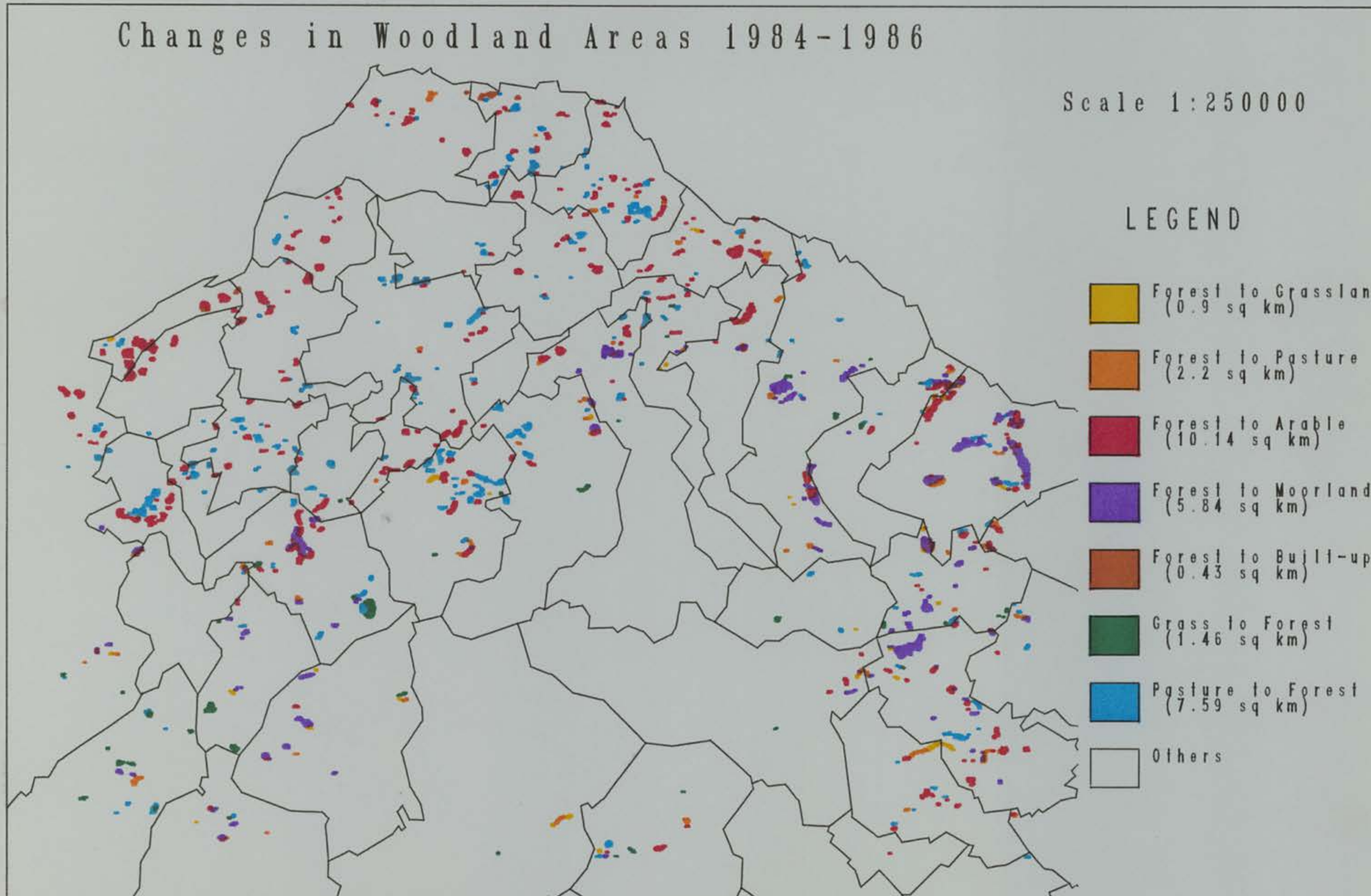
Map 5.2 Automated plotting of the TM image classification (14 September 1986)



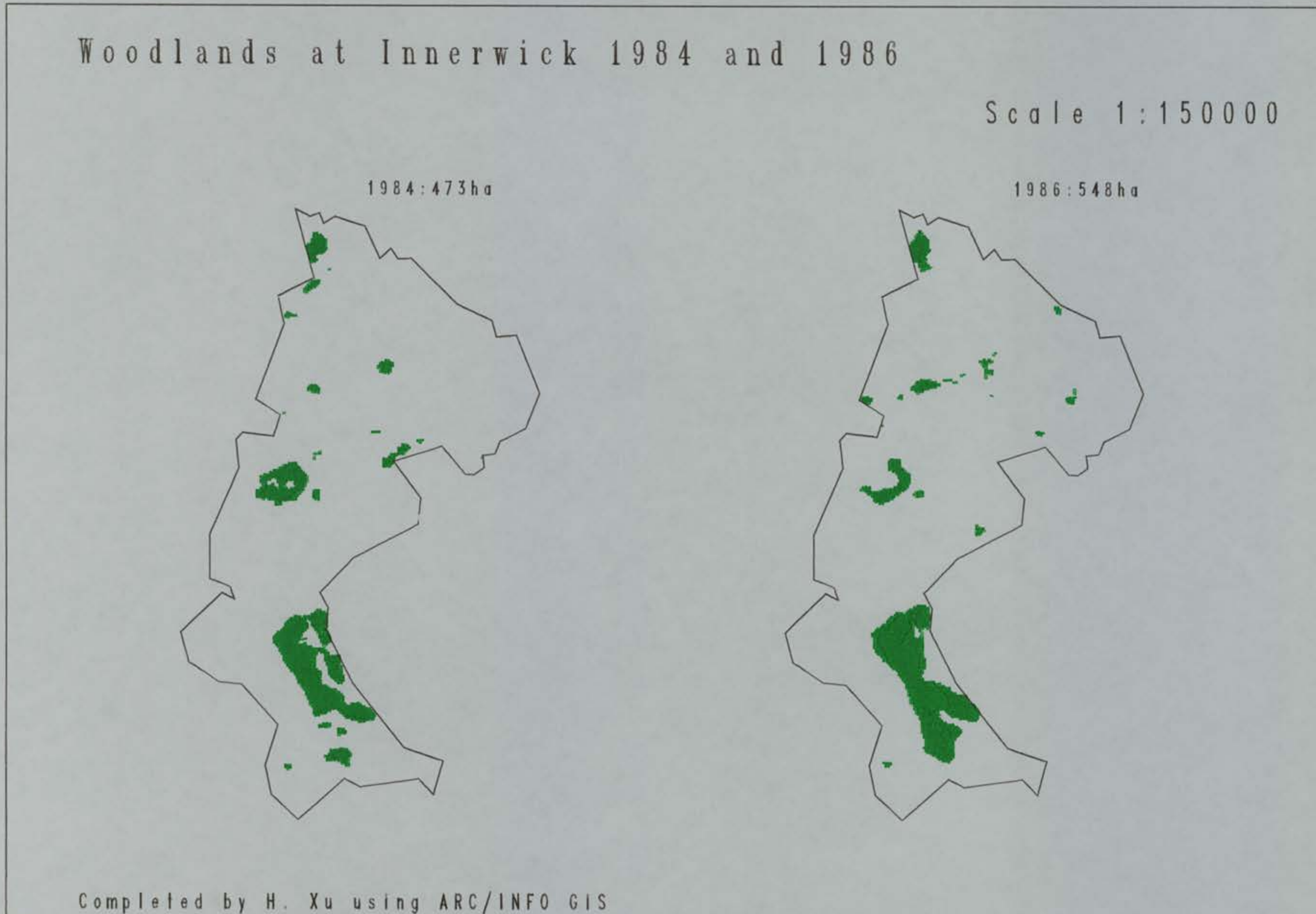
Map 5.3 Areas of afforestation 1984-1986



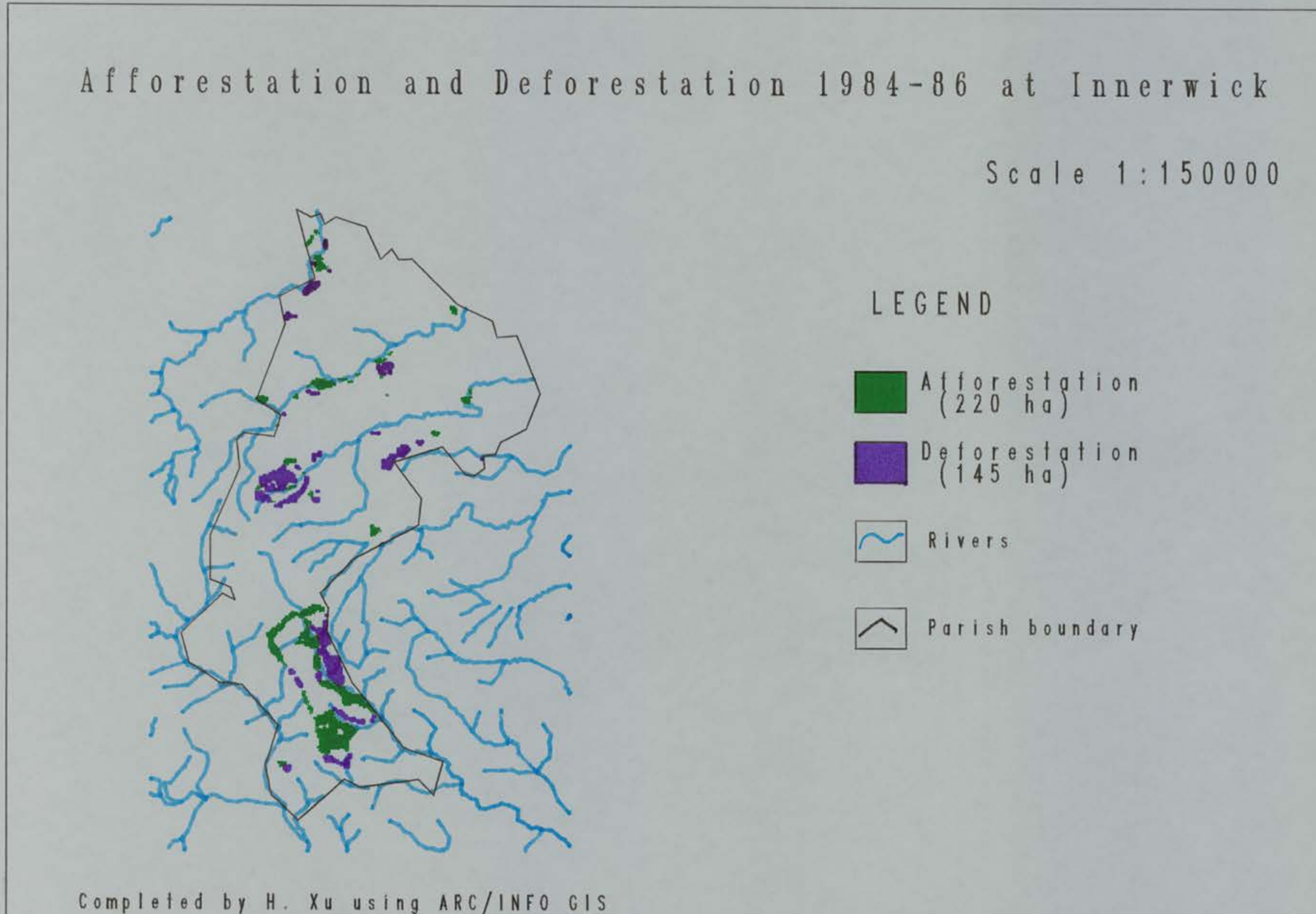
Map 5.4 Areas of deforestation 1984-1986



Map 5.5 Changes in woodland areas 1984-1986



Map 5.6 Woodland area at Innerwick: 1984 and 1986



Map 5.7 Afforestation and deforestation at Innerwick 1984-1986

CHAPTER VI

DISCUSSION AND EVALUATION OF THE RESULTS

6.1 Monitoring Changes in Land Use/Land Cover in South-East Scotland

This thesis combines the development of a technical method and its application in a selected case study. The overall aim of this research has been to investigate and evaluate an alternative method for the monitoring of changes in land use. In order to achieve this aim, the research considered different data sources available and explored their applications using state-of-the-art approaches where possible. In this context, the analysis of remote sensing data and its integration with GIS demonstrated their potential to be an operational tool for land use study. To compare with and to complement the imagery analysis, other data sources were utilised to extract information on changes in regional land use. For example, agricultural statistics at parish level have proved to be extremely useful in a long term retrospective study of land use, especially when computer mapping of the parish summaries makes the analysis even swifter and more systematic. The inter-relationships between different data sources and methods are discussed in the following. An approach including a technical method has been constructed for monitoring land use/land cover with an integration of different sources and methods.

This research can also be viewed as an application of state-of-the-art techniques in land use monitoring. It demonstrated the great potential of the analysis of Landsat imagery as well as the importance of integrating different data sources and methods. This was achieved by identifying changes in land use for the test location in south-east Scotland. The analysis of the parish summaries dated back to 1947 and provided a basis for demonstrating changes in land use in the study area over the post-war period. Analysis of Landsat images in conjunction with GIS revealed spatial changes in land use between 1984 and 1986, and thus presented a way forward for a detailed study of changes in land use incorporating GIS and analysis of digital satellite imagery.

Therefore, this research combined the development of a technical method and an application study. The major findings of the thesis can be summarised in the following.

6.1.1 Detection of changes in land use in South-East Scotland

Changes in land use for the test location in South-East Scotland were detected both spatially and quantitatively, using a combination of different data sources. Analyses of different data sources proved complementary to each other to give a complete picture of regional land use extended over a period of forty years. The land use survey was carried out mainly in two agricultural contexts: one concerned alterations to the spatial arrangement of fields, as shown by the analysis of multi-date digital Landsat images, and the other dealt with changes in the amount of land allocated to different land uses and the relative rates of change in different areas. The latter were indicated and revealed by the analysis of the parish summaries from 1947 to 1987.

On their own, analysis of agricultural statistics at parish level can enable the general characteristics of regional land use to be constructed. In this case, the analysis of the parish summaries elucidated patterns of the spatial distribution of land use as well as indicating the trends and rate of changes in land uses. With a built-in framework of Great Britain at parish level, the CAMAPGB1 and GRIDMAP packages, which are available at Edinburgh University, offer an efficient means of cartographic representation of the parish summaries. Areal variations of different agricultural activities and land uses were revealed by analysing the mapped series of different variables. Quantitative comparisons over time were made to assess temporal changes. Careful choice of the scaling factor and class intervals was used to emphasise various aspects of the data and to show different aspects of land uses. Supplementary to the findings of cartographic representation, statistical data for each variable were plotted against time to demonstrate temporal changes in land use in the study area over the same time period, and therefore to establish possible relationships between different variables through their concomitant changes (see Figures 4.4-4.11). This was further supported by the correlation analysis of different variables (see Appendix 3).

A general picture of regional land use was constructed through cartographic representation of the parish summaries and their graphic plotting for temporal monitoring and correlation analysis. Improved efficiency of these processes was achieved with the help of computer-assisted analysis.

The results of this study show a continuation of the pattern as revealed by previous studies (*e.g.* Parry, 1973) in that land use zones in the Lammermuir Hills area changed from sheep farming on rough grazing land on top of the Hills to cropping and livestock raising on the higher ground bordering the Hills and then to intensive lowland arable farming. Apart from the basic pattern, certain trends of changes in land use were identified in the analysis. The importance of arable farming has been increasing and the upper limit of cultivation has expanded towards the uplands while areas of grassland and rough grazing have been decreasing. Reflecting the growing afforestation, areas of woodland on farm have expanded through time.

Within arable farming, an increased acreage has been sown to grain. Barley has been predominant, followed by winter wheat. Oats now occupy only a small portion of tillage and have been decreasing significantly. Stimulated by high support prices within the Common Agricultural Policy, oilseed rape has been grown by farmers in the lowland parts of the study area since 1980 and this crop is now an integral part of crop rotations. In contrast, root crops such as potatoes, turnips and swedes have suffered a decline in acreage and significance. However, higher yields of potatoes have meant that this crop is still a major contributor to farm output.

The decline of rough grazing can be mainly attributed to its conversion to improved pasture and to the spread of afforestation. Sheep rearing is the major economic activity on rough pasture, though higher densities of sheep can be found in those parishes with a high proportion of land under grassland since improved grassland can sustain higher sheep numbers.

In general, changes in land use and the inter-relationships between different variables were explored by means of a combination of different methods. The long term availability of agricultural statistics makes them advantageous and unique for a long term retrospective study of land use. For instance, this research extended back to 1947, marking the start of the major post-war commitment to self sufficiency in agriculture by the British Government, and therefore it is regarded as an important date in British agricultural history. Some of the impacts of agricultural policies were revealed in the results. While remaining a valuable data source for a long term retrospective study, the analysis of statistical data also provided information on regional land use/land cover, which was significant in assisting with the interpretation of Landsat imagery in this research. Meanwhile, the difficulties in identifying precisely the locations of agricultural activities due to the absence of detailed individual farm data in agricultural statistics could be overcome and supplemented by the imagery analysis.

Landsat images can be used for examination of the alterations to the spatial patterns of land use/land cover. In this study, the analysis of images for 24 April 1984 and 14 September 1986 mainly played a role of further exploiting the computer-assisted techniques in association with the application of remote sensing data in land use/land cover study. However, some of the characteristics and advantages of using remote sensing as an operational technique were also revealed, *e.g.*, the consistency of remote sensing data over a large area and the ability to show detailed spatial location of land cover. However, there is still the potential to improve the nature of this type of application. While remote sensing offers the means to acquire many new data types relevant to the analysis of environmental problems, computer-based systems (*e.g.* CAMAP and ARC/INFO GIS) are increasing the capability for assembling, storing, and analysing data in a framework designed to provide a datum to facilitate resource management decisions associated with such problems.

This study has shown the great potential of Landsat imagery in mapping spatial distributions of land cover/land use types and determining their areal extents. The two images of 1984 and 1986 provided useful information on regional land use. The Landsat MSS Spring scene offered a good chance for crop identification while the Landsat TM Autumn scene helped clarify the difference between arable crops and seasonal grasses. By going through the procedures of geometric correction, selection and progressive refinement of the training data, integrated classification of land use/land cover, post-classification majority-mode filtering, accuracy assessment and transference of digital image data to ARC/INFO GIS, and quantitative comparisons of classification results for different dates, changes in regional land use/land cover were detected and shown both spatially and aspatially (*e.g.* Maps 5.3-5.7). Spatial distributions were mapped using functions within ARC/INFO and the attributes were calculated subsequently, as explained in Section 5.5. The products, such as graphics showing the locations of all individual category changes, could be provided quickly and inexpensively as specialised output from the computerised GIS, *e.g.*, Map 5.5. Spatial data on land use/land cover change could then be used directly for updating the existent maps and statistical data provided that the error assessment satisfied specified requirements.

Acceptable results, with 88% accuracy for TM image classification and 82% for the MSS image classification, were obtained. The required training data were carefully selected with the help of the yearly Farm Cropping Plan of the Bush Estate and the analyst's *a priori* knowledge of the area. The progressive refinement of the training data further improved the classification accuracy. The integrated classification, using a Maximum Likelihood Classifier, offered advantages over a single object identification in that it considered the fact of interaction of multi-factors in any composition of land use/land cover. Manual segmentation/stratification of images prior to classification helped to avoid certain obvious errors, *e.g.*, pixels classified as built-up areas on areas known to be moorland, and built-up areas misclassified as moors could be readily excluded. The majority-mode filtering of the classified images removed isolated pixels and reduced the number of unclassified pixels whilst retaining the number of classes in the resultant images. Accuracy assessments evaluated the classification performance and confirmed the acceptability of the classified images. Transference of the digital imagery data into ARC/INFO GIS by tracing the outer-edge of the boundary pixels between classes enabled the vectorising process to approximate more closely to the image data.

Thus, detection of changes in land use/land cover has been carried out using the image processing system and ARC/INFO GIS. Information on changes in a specific type of land use/land cover for a defined area can then be obtained in relation to its spatial distribution (*e.g.*, Map 5.7). This information can be compared with other data stored in the GIS, such as the parish summaries (see Section 5.5.2). One of the major objectives of the research has thus been achieved.

6.1.2 Benefits of integrating remote sensing and GIS

As a major achievement of this study, the improved analysis showed the benefits of integrating different data through ARC/INFO GIS. It provided an efficient use of the ancillary data required by remote sensing analysis and enabled relationships between data-sets to be explored and examined. For example, the overlay of river networks or road systems helped the analyst to identify and allocate certain features on the image in the selection of training fields prior to image classifications. Meanwhile, an overlay with parish names and boundaries indicated the major farm type and land use in certain areas in conjunction with the analysis of the parish summaries. Here *a priori* knowledge of the geographic area to which the remote sensing data apply was of substantial importance in the analyst's active involvement.

Remote sensing analysis generates a wide variety of data which could be used as an input to update GIS data planes. Classified images showing land use/land cover types could work on ARC/INFO as a final output, or could be compared to assess changes over time, or even be selected (Clipped) for a case study in a defined area such as a parish. One example was the analysis of changes in forestry for the Innerwick parish as shown in Map 5.6 and Map 5.7 in Section 5.5.2. Not only do these maps present the spatial location and area of regional land use/land cover, but also they reveal changes in land use/land cover, in particular they reflect the internal variation of land use/land cover. Indeed, the synergism of remote sensing and GIS leads a step further towards the production of spatially accurate, timely data on land use/land cover parameters that can be processed into information relevant in management decision-making.

6.1.3 Combination of different data and methods

A combination of different data sources is required for an integrated study of land uses. These data sources and the corresponding approaches work both in parallel and supplementarily. As demonstrated in previous sections, each data source can work on its own and reveals certain aspects of a regional land use/land cover. They can achieve similar objectives in parallel, but their complementary role to each other mainly exists in the following aspects: time, space, level of detail and type of information.

First, the time period of each data source available is different and therefore they need to supplement each other to cover a required period. For example, Landsat images of the study area were not available until the mid-1970s and aerial photographs only date back to the 1950s while agricultural statistics have been collected since 1866. As for analogue maps, they usually provide information for a certain time of year or a period of several years. This research is dated back to 1947 and thus it is essential to use a combination of data sources. The advantages and limitations of each data source have been analysed in Chapters 3, 4 and 5.

Furthermore, each data source has a different spatial form. Landsat digital images provide data about the Earth's surface in raster format according to the spectral reflectance characteristics of objects. Agricultural statistics are the aggregated results in numerical form for a certain geographical unit (in this case, the parish) without providing detailed spatial locations of each reported item.

In addition, each data source provides information at different levels of detail. Landsat digital images record data from platforms 700 to 940 kilometres above the Earth's surface and often result in low spatial resolutions and limited detail, but they provide a synoptic view of a given area at a large scale. Aerial photographs give information from altitudes of a few thousand feet and thus have higher resolutions and more details than Landsat data. Agricultural statistics data in the form of the parish summaries do not provide accurate information in relation to the precise location of land use activities. Also, the utility of information at parish level is limited due to the lack of suitability of the parish as the basic unit for a land use study.

The type of information each data source can offer is also rather variable. Landsat images and aerial photographs offer spatial information in map or digital format whilst agricultural statistics come in quantitative form, though with a spatial character, in this case at the level of individual parishes.

With respect to the method of using each data source, the complementary roles of using Landsat images and agricultural statistics were analysed in this research with an integration of descriptive and mathematical methods. These methods both reflect and involve the application of developments in modern technology, especially in computer-assisted systems. Analysis of agricultural statistics showed an example of a computerised application of a conventional, descriptive approach on a traditional data source while satellite imagery analysis revealed the potential of remote sensing as an operational technique of extracting information from newly available digital data.

Again, the use of Landsat images and agricultural statistics revealed different methods for interrogating and analysing the data. Although some practical problems and difficulties have been identified, the combination of the two data sources demonstrates its substantial value to meet a specific objective. For instance, in this study, they are required to work together to produce results concerning changes in land use/land cover for the test location in South-East Scotland. Whilst the analysis of the parish summaries revealed the general pattern of regional land use and trend of changes during the past four decades, the utilisation of digital remote sensing data presents a way forward to identify the spatial distribution of land use/land cover and to monitor changes in land use/land cover.

6.2 A Critical Review of the Methods Adopted

It is reasonable to believe that through an effective integration of data sources, methods and new techniques, the best results have been achieved with respect to outlining changes in land use/land cover in South-East Scotland under present availability of data and techniques. However, it is also recognised that there are limitations in both data sources and the methods used. These limitations are discussed below with a view to suggesting improvements for future research.

6.2.1 Limitations in using the data sources

General limitations of the data sources used in the research have been pointed out in Chapter 3. What is discussed here is mainly concerned with the problems and difficulties identified and encountered in the utilisation of the data sources in this thesis. The discussion will focus upon the use of agricultural statistical data and the Landsat images for monitoring changes in land use/land cover.

(1) Agricultural statistics:

Difficulties were encountered in using agricultural statistics at parish level for determining locations of land uses within a parish. As discussed in Chapter 3, these problems mainly stem from the nature of the collection of the data for the estimates of agricultural production with little reliance upon the accurate locations of the land to which the summaries refer, the consolidation of returns from individual farms into the parish summaries, and amalgamations of small parishes. Also, using parish as a basic spatial unit is lack of suitability for a detailed land use study.

Changes in land use/land cover in South-East Scotland since the late 1940s were demonstrated by mapping the parish summaries, monitoring temporal changes in the study area and applying a correlation analysis of land use variables. Bearing in mind the limitations of the parish summaries, caution is exercised in using the data in land use/land cover study. The results have been taken as inaccurate in detail, but reliable in their general trend.

(2) Landsat images:

The limited availability and the irregularity with which data have been acquired often limit the use of Landsat images. Landsat images of Scotland first became available in 1975 (MSS data) and 1986 (TM data). Usable imagery is required on a routine basis in order to use satellite imagery successfully as a regular input for land use monitoring in Scotland. But this is often affected by cloud cover, especially in upland areas. The effect of clouds and shadows in the image often precludes a complete study of the image and thus requires supplementation by other data sources. Apart from the fact that areas under clouds or shadows fail to give any useful information on land use, the existence of clouds and shadows may cause confusion and then affect the overall classification performance. For instance, some of the dark shadowed areas in the TM image for this study had very low spectral reflectance values and therefore were misclassified as water, whereas they were actually crop lands. As aforementioned, there is only a small chance of obtaining cloud free images for Scotland (see also Legg, 1991)! Thus the incorporation of ancillary data such as land use surveys from other sources is often helpful and necessary. Gurney (1983) has reported that contextual methods can be used in separation of cloud and cloud shadow from the remainder of a satellite scene. The synergism of remote sensing and contextual data is of particular significance to achieve this. Substantial contextual knowledge of the ground situation is also needed to counter the subtlety and diversity of the changes in land cover since one of the characteristics of land use in Scotland is its complexity within a short distance, while the spatial resolutions of Landsat images (79 m x 79 m for MSS and 30 m x 30 m for TM data) may lead to difficulties in studying the small parcels of land in different uses. Fortunately, in the TM image of 14 September 1986 used in this research, the classified clouds and shadows accounted for only 1.24 per cent of the pixels in the whole study area.

Another problem of this study arose from the deficiency of only two images (24 April 1984 and 14 September 1986) for monitoring changes in land use. The analysis based upon these two images played the role of testing and exploring the utilisation and methodology adopted. The fact that these images have different spatial resolutions and were acquired in different seasons only exacerbates problems in making comparisons between images in order to assess changes in land use/land cover. However, they served the purpose of enabling the development of a methodology for examining land use change.

For a good comparison, it is important to have images registered accurately to a standard base map. In this research, the registration of the Landsat images to the British National Grid coordinates was performed by geometric correction. As discussed in Chapter 5, despite concerted efforts, the geometric correction performance on the MSS image remained less than satisfactory due to the difficulties in identifying locally sufficient ground control points on the image. This formed an inherent problem for the comparison of classification results of Landsat images for different dates.

Limitations in carrying out the imagery analysis also arose from the definition of a category of land use/land cover, such as grassland or pasture or arable land. By broad definition, grassland is usually managed and sown, including in this case temporary grassland, meadow grasses and some recreational land uses, whilst pasture is mainly permanent grassland with intensively grown grasses without being sown for at least five years, and arable land consists of crop land and fallow. These three land uses may have a very similar spectral reflectance at the time when the image was acquired. Therefore classification errors may occur and thereby affect the overall classification performance. For the TM image classification, over 70 per cent of the pixels misclassified as grassland were attributed to arable land and nearly 60 per cent of errors for pasture were attributed to grassland.

Whilst post-classification filtering helped to remove isolated pixels and reduce the proportion of the unclassified pixels, it affected the classification to a certain extent. Small areas may be merged into their neighbouring land use, *e.g.*, a farm house or a road next to cropping fields may be represented as arable land on the classified image after the filtering. Considering the characteristics of land use in Scotland, where subtle variations occur within a short distance, the effect of merging cannot be ignored completely.

Although the integrated classification offers advantages over single theme identification, difficulties were encountered for delineating certain feature classes with single date images. It is not ideal to carry out an integrated classification on the basis of the analysis of a single image. Multi-temporal imagery analysis is regarded as essential to solve this problem. More images at higher cost in a realistic time need to be analysed in order to ensure the quality of a classification and the pragmatic capability of routinely monitoring changes in land use/land cover. As Mather (1987) argues, "in order to distinguish between some types of vegetation, it is necessary to use multi-temporal imagery, that is, imagery of the same area collected at different periods in the growing season".

(3) Lack of compatibility between imagery and statistical analysis

One drawback of the research methodology is the lack of complete compatibility both temporally and spatially between analysis of the two different major data sources.

The statistical analysis used data for the period from 1947 to 1987 while the imagery analysis was limited to images for two dates (24 April 1984 and 14 September 1986). Therefore, it is virtually impossible to compare directly the results from these two approaches. Whilst they are supplementary to each other in terms of time difference, theoretically they are also complementary in methodology and in the content of information extracted from different data sources. However, for this research, they work independently to a large extent although comparison between remote sensing analysis and the parish summaries was carried out for a selected parish as in Section 5.5.2. In spatial terms, there are difficulties in integrating the two data sources and their results to supplement each other's findings in a systematic way because of the fact that imagery data give information based on the pixel size while agricultural statistics are summaries aggregated from individual returns to the parish level. Comparison between Landsat imagery analysis and the parish summaries for the selected parish of Innerwick demonstrated some of these difficulties.

However, while being a drawback, this is also a challenge to try to improve upon in a future research context.

6.2.2 The importance of error analysis

In recognising the problems in Landsat image analysis, it is of importance both from a theoretical and a practical point of view to perform an error assessment and to quantify the effects.

As pointed out by Singh (1989), the change map product of image classifications generated from a single date of Landsat data is likely to exhibit accuracies similar to the product of multiplying accuracies of each individual classification. Hence a large number of erroneous change detections can be produced since an error on either date gives a false indication of change. For this study, on completion of the accuracy assessments, the overall accuracy for the TM image classification was 88% and for the MSS image classification it was 82%. These figures have to be carried forward into the change detection exercises. Thus the overall accuracy of the change product is likely to be 72% (88% x 82%) which is less satisfactory in meeting the requirements for change detection of regional land use. Based on the contingency tables of accuracy assessments for both images, adjustment to change detection products have been attempted taking into account of the commission and omission error rates, as demonstrated in Section 5.5.

As discussed in the last subsection, error propagation may be attributed to several aspects. The less satisfactory registration of the MSS image to the BNG forms an inherent problem for the comparison of the classification results. Any shifting effect in the boundaries of each image classification can lead to a false indication of change detection. Also, errors could be incurred during the transference from data (with 50 x 50 m^2 grid cell) to vector data. The problem can be exacerbated by the different spatial resolutions of MSS and TM images. Finally, the use of the majority mode filter on the classification results of the TM image versus the MSS image may cause problems too because of the difference in their spatial resolutions.

As a consequence, the results and the usefulness of the change detection might be subject to the suspicion that it is more a product of the method than of reality when all these above-mentioned possible errors were taken into account. For example, referring back to Map 5.5 and Map 5.7 which presented changes in woodland areas between 1984 and 1986, spatial correlation has been demonstrated for most changes. Obviously the changes for these two years are within the error boundaries of the two image classifications as discussed in Section 5.5.2. Therefore error analysis in any remote sensing and GIS work must be given sufficient attention in order to ensure acceptable outputs. This must form an important aspect of further studies using similar data.

6.2.3 Further improvements in the interface between remote sensing and GIS

The research results have demonstrated the potential and advantages of the synergism of remote sensing and GIS in land use studies. It has put the integration of the two technologies into realisation. However, using the present approach to integrate the remote sensing data into ARC/INFO GIS is much too time consuming and demanding of intensive CPU time. Thus the process is generally slow and requires large amount of computer space. Further improvements are needed to develop more efficient means of achieving results of the same order. It is believed that working in a raster environment is faster than in the vector environment, but no conclusive experimentation has been undertaken to demonstrate this in this research due to time and cost limitations. There is not a fully compiled operational geographic information system available in raster format for this purpose. In addition, the interface between remote sensing and GIS is a research frontier that demands joint research between computer scientists and applications scientists. However, along with the rapid development in computing analysis, the use of more powerful and more user-friendly workstations with increased capacity will be available to meet the requirement in the near future.

6.3 Comparisons with Other Work on Land Use and Land Use Change

Some comparisons are made here with other work on land use and land use change in terms of different time periods and spatial locations in order to evaluate the methodology adopted and data sources used in a practical way.

In the U.K., maps, aerial photographs and field surveys have usually been the major sources used for the investigation of land use changes. Ordnance Survey maps have always recorded information on land use although they were not intended as land use maps. The criteria used to determine what should be mapped relate to the permanence of features and to their contribution to the topography being presented. They therefore contain a great deal of information about built-up land but much less about rural land, except in respect of semi-permanent features, *e.g.*, woodland and semi-natural vegetation. Cultivated land cannot be identified directly although it occupies most of the land without symbols, which is broadly equivalent to the 'crop and grass' of the agricultural census (Coppock and Kirby, 1987:P33). The principal difficulty in using Ordnance Survey maps as a source of mapping land use/land cover is that they relate to the situation on the ground at a wide variety of dates.

Therefore, these maps are usually used as supplementary data, *e.g.*, base maps for the collection of data in the fields or from remote sensing (Coppock and Kirby, 1987; Wathern *et al*, 1988).

Aerial photographs are a regular and reliable data source for land use study, though they may not be frequent enough to enable study of the rapid changes in the upland land use (Coppock and Kirby, 1987). It is also possible to analyse photographic images quantitatively, though the processes entailed are laborious and highly time consuming.

Field survey can usually provide data required for a specific purpose, but complete coverage of a large study area would be significantly more expensive than sample surveys to produce results at a desired level of accuracy. Field surveys also require suitable organisation or sufficient skilled manpower.

Another popular data source for land use studies is agricultural statistics. The attractions of statistical sources are that they are already in numerical form and may provide low-cost solutions to the collection of data. In addition, these data are available for the whole of Scotland on a reasonably consistent basis for any area which can be constructed with the parish as the building block. The annual agricultural census has been collected since 1866, but it is not primarily a record of agricultural land use and DAFS has not had any need to maintain an accurate record of the way in which agricultural land is used. No field checks are made of the reliability of the returns, reliance being placed upon plausibility tests and comparisons with returns for the preceding year. Equally unfortunately, the information on changes in agricultural area does not indicate whether the land transferred is cultivated land or grassland. However, despite all the limitations, agricultural statistics have been widely used in previous studies. Sometimes only one year's data have been used to represent the agricultural status for a certain region (*e.g.*, Coppock, 1964 & 1976). Sometimes several years' data have been used to examine changes in land use over a given time period (*e.g.*, Robinson, 1988 and Wathern *et al*, 1988). Sometimes they have been cartographically represented with the help of computer mapping (Coppock, 1976) and sometimes they have been simply shown quantitatively (Wathern *et al*, 1988). Also, some studies (e.g., Ilbery, 1983) have made use of information from farmers while others (e.g., Bowler, 1985) have focussed upon the impacts of the Common Agricultural

Policy and other government policies on agriculture. However, it is felt that no existing secondary sources, *i.e.*, cartographic and statistical sources, whether singly or together, are capable on their own of providing adequate information on the structure and changes in land use without leaving gaps and problems of incompatibility (Coppock and Kirby, 1987; Mather, 1979). Therefore, it has often been found helpful to use combined data sources to construct a complete picture of regional land uses. For instance, parish summaries and interpretation of aerial photography were involved in the work done by Ilbery and Evans (1989). For a long term study, this is even more necessary (*e.g.*, Parry, 1973).

As a relatively recent data source, Landsat digital data are directly available and readily amenable to analysis using digital computers. In the case of surveys of large areas, the use of Landsat data has been predominantly dictated by the economic considerations of their comprehensive coverage. Although much of the literature describing the use of Landsat imagery in making inventories of vegetation and crops is of limited value in advancing understanding of the techniques and use of remote sensing, it does demonstrate collectively that remote sensing is capable of identifying many of the land cover types of interest to the strategic planner.

In the U.K., there is remarkably little relevant published literature prior to the mid-1980s, concerning the applications and suitability of remote sensing for monitoring land use change (Wyatt, 1984). The reasons for the comparatively slow adoption of remote sensing as a tool for monitoring land use/land cover change are complex. For example, there are a number of technical problems and there have also been educational and promotional difficulties associated with the introduction of any new methodology. In practice, cloud cover often seriously limits the choice and restricts the use of satellite data for routinely monitoring land use change in upland areas. Good coverage of imagery for Scotland from the MSS sources exists for 1975 and 1984, but TM imagery is not available for large parts of Scotland for any date before 1986 and complete TM coverage does not yet exist. This is mainly affected by cloud conditions and whether the sensors were switched on when a satellite passed over the country (Coppock and Kirby, 1987). Landsat digital data represent an obvious source of information on land use/land cover either on their own, by way of image classifications, or as a graphic presentation to complement conventional aerial photography.

Digital image classification of land cover types is a natural line of investigation that has been followed in many parts of the world in the last decade (*e.g.* Kelly and Hill, 1987; Rubec, 1980). The potential and applications of Landsat images have been well appraised. Some examples in the U.K. are the work by Hogg and Stuart (1987), Weaver (1987) and Williams (1987). Relatively few of these studies have produced entirely satisfactory results, indicating that the computer-assisted classifications are either not yet fully developed or are not capable of coping with British conditions. In fact, both reasons are relevant. Because the land use/land cover parcels are relatively small, because the low sun angle at this latitude reduces reflectance values and because the difficulties in obtaining cloud free images, conditions for numerical analysis in the U.K. are less than ideal. However, the work done in Scotland to date has helped to appreciate the potential of the system for Scotland. For example, Hubbard and Wright (1982) carried out an imagery classification of primary land cover types of mainland Scotland, while the work by Weaver (1987) involved the use of MSS data to study vegetation succession in upland Scotland. Substantial contextual knowledge of the ground situation to counter the subtlety of the changes in land cover is often needed, as one of the characteristics of land use in Scotland is the complexity within a short distance. Therefore, incorporation of ancillary data and *a priori* knowledge of the study area are of special value. The significance should also be emphasised of the active involvement of the analyst in using contextual and other information present in the image to guide and to carry out data analysis. Most techniques for classification improvement require that the analyst has a detailed understanding of the objects of interest and their relationship with ancillary data before attempting to improve the classification (Hutchinson, 1982).

The data sources and methodology used for this study differ from others in that, firstly, it involves the use of data from a combination of several sources and, secondly, an integrated image classification of land use/land cover is carried out instead of single resource identification and, thirdly, it demonstrates the successful realisation of the synergism between remote sensing and GIS. Each of these points has its significance and they are discussed below.

Employing agricultural statistics and Landsat images as major data sources, aerial photographs and Ordnance Survey maps and other statistics (*e.g.*, Forestry Commission statistics) have been used in this thesis. The combination of different data sources is required for a complete picture of the structure of land use in the study area and for exploration of the potential of the data analysed. They work both in parallel and supplementarily as elucidated in Section 6.1. The research has confirmed the expediency and significance of the parish summaries as a traditional data source in a long term retrospective study of land use/land cover and has also revealed further potential for their more efficient use following the recent rapid development in computer mapping techniques. Agricultural statistics, Ordnance Survey maps and aerial photographs have been found helpful in obtaining satisfactory results from imagery analysis both directly and indirectly in that they can be used together to identify certain ground features or in assisting the analyst to acquire knowledge of the study area in general. Indeed, a successful application of image classification scheme requires that both spectral and spatial characteristics of the new data, and the inferential and deductive capabilities of the human interpreter be employed (Merchant, 1982).

In comparison with single resource identification, integrated classification of land use/land cover has the advantage of taking into account the fact that any process in land use is the result of interaction of many factors which compose the pattern of a regional land use. The results obtained are more pragmatic and more realistic, though only achieved with greater effort.

The adopted approach for detection of land use/land cover change in this study was the comparative analysis of independently produced classifications for different dates. This method of change detection holds the most promise because data from the two dates are separately classified, thereby minimising the problem of normalising for atmospheric and sensor differences between two dates, although the change map product of two Landsat image classifications is likely to exhibit accuracies similar to the product of multiplying the accuracies of each individual classification (Singh, 1989).

Last but not the least, this research attempted to put the synergism between remote sensing and GIS into practice instead of remaining as theory, prediction or an abstract ideal.

The integration enhanced the potential of each and presented a way forward for land use study. The full potential of remote sensing and GIS is only exercised when the synergism created by the two technologies to provide data and analysis never before possible is used in the broadest possible definition of a given application.

Thus, a full picture of changes in land uses was constructed in this research by means of a combination of data sources and approaches. Not only were general patterns of regional land use demonstrated in a quantitative form or by their spatial distribution, but also the study exemplified a way forward to show both the spatial distributions of land use within a region and the corresponding aspatial attribute information. The final outputs enabled identification of the exact nature and areal extent of the changes as well as their spatial locations. Map products also provided information about the relative sizes and shapes of land use/land cover changes. On the other hand, information on the number and amount of changes that occurred within certain land use/land cover categories could be used to measure the dynamics of land use in an area. Thus it is clear that both maps and statistical data on changes are needed to provide a complete and accurate picture of what is actually happening to the land resources in an area.

6.4 Implications for Future Studies

Based upon the analysis and evaluation of the results in this study, it is felt that some suggestions can be put forward, in respect of achieving a better outcome both using current data and facilities and with technical improvements made to several aspects of the system.

Firstly, the use of the parish summaries should be made to the broadest extent, confirming their significant value in land use studies, especially for long term retrospective studies. As suggested in Chapter 4, using the parish summaries in a more detailed correlation analysis or a multivariate analysis for a few years could have revealed fuller potential of the summaries as a source of information for studying agricultural land use as demonstrated by Robinson's work (1981 and 1988). Also the parish summaries can be used to best effect by classifying type-of-farming areas or by referring to the non-land use items they contain, such as farm size and the labour force. As a readily available and easy accessible data source, they can be incorporated into information systems for efficient handling. Advanced techniques can also be developed for rapid combination with data extracted from other sources, such as Landsat satellite imagery.

In assessing the cost-effectiveness of remote sensing, further potential of remote sensing and GIS can be explored when the two technologies are more effectively integrated. Remotely sensed data in their readily available digital format have the potential to improve both the quality and quantity of data available to information systems and in some ways to contribute data never before available to such systems. Over the twenty years since the launch of the first Landsat satellite, remote sensing has progressed from an experimental curiosity to an operational technique. It has increased in acceptance as a useful and an essential tool for studies of the Earth as well as for monitoring and measuring its resources. However, automatic techniques of data extraction from remote sensing imagery are not fully operational yet. Problems concerning the synergism between Landsat imagery analysis and information systems usually relate to image quality, resolution, volume of data and image classification performance. There is a need for further exploitation of the technologies and techniques involved or associated with remote sensing under the growing pressures on the environment from human activities to climate change. In this research, data transferred from ARC/INFO GIS to the GEMSTONE-35 image processing system mainly helped the analyst to acquire knowledge of the study area and visually identify certain features of the imagery. The limited capacity of the system and the large volume of imagery data to cover the study area precluded an automated overlay of ancillary data and spectral band data in imagery classification. Also, a lot more could have been achieved in data transformation and manipulation from classified images to ARC/INFO GIS with improved efficiency.

With respect to image classification performance, multi-temporal analysis is essential for an integrated classification of land use/land cover, especially when clouds and shadows often affect image quality. More images taken in different seasons of the same year should be used for analysis and classification to achieve better accuracy. Also images over different time periods need to be used to monitor routinely changes in land use. All of these can only be realised at higher cost with more time available. Again, the availability of the required hardware and software is essential to produce effectively a classified data-set with an adequate classification accuracy and appropriateness for a particular application.

In examining the trends and possible consequences of current research, the analysis of errors in GIS is gaining more attention along with the increasing use of GIS in Earth resource assessments. This is of substantial significance to ensure the quality of information held in and derived from spatial databases (*e.g.*, Chrisman, 1987). Also, cloud cover is the single largest factor preventing the routine use of data collected with optical remote sensing instruments in the U.K. To overcome the cloud cover problems, other remotely sensed data may be involved, such as microwave data with its cloud penetration ability or the cloud filtering of the AVHRR (Advanced Very High Resolution Radiometer) data through registration of images for different dates based on the maximum value of the Normalised Difference Vegetation Index (*e.g.* Cihlar *et al*, 1990). New microwave satellite systems, such as ESA's ERS-1 (launched on 17 July 1991), have the ability to gather weather independent information on classification of land cover. The Synthetic Aperture Radar (SAR) carried on board the ERS-1 spacecraft will provide very high resolution (25 m^2) imagery of much of the Earth's surface. Similarly, the fine resolution of SPOT data (10 m to 20 m) should be of help for a detailed land use study. Following the successful launching and commissioning of SPOT-2 in 1990, the advantages of the improved image quality should be made use of where it is economically viable. Again, difficulties may arise as SPOT lacks the mid-infrared information of the TM sensors, which may preclude accurate census studies of crops (*e.g.* Atter and Townshend, 1985). However, it is clear that when the next generation of satellites has both the geometric resolution of SPOT and the spectral resolution of Landsat TM, classification of land cover will be greatly improved and routine monitoring of multiple classes will be possible.

Lastly, as Estes (1982) contended, the most significant research area is "the area which involves the interface between research being conducted in the area of artificial intelligence and remote sensing image analysis and geobased information systems." It is believed that further research on expert systems "promises to bridge a gap that has in the past existed and to a very real extent continues to exist today between remote sensing discipline experts and the eventual users of information derived from geographic information systems." As the temporal and spatial frequency and the format of remote sensing data tend to go beyond the capacity of many qualitative models developed around data from conventional sources, and of the information systems which support them, further development in application of remote sensing is required to take advantage of "the synoptic, spatial, temporal and functional characteristics of remotely sensed data" (Estes, 1982). Expert systems will allow use of the knowledge of experts in the area of applications and of image analysis. The past several years have seen much progress in the development of expert systems, *e.g.*, Millette (1990) reports that the expert system approach holds promise for spectral band selection for remote sensing analysis. Also, Li (1990) described a classification procedure using an expert system in the context of a 3-D target recognition task. Meanwhile, neural networks for classification are showing their potential for further studies towards an understanding of global change. In the U.K., Corr *et al* (1988) developed a knowledge-based segmentation system to achieve superior segmentation and subsequent classification accuracies. The paper by Wyatt *et al* (1988) also explores alternative approaches to the discrimination and classification of upland vegetation. These include knowledge-based classifiers and spectral mixture modelling, with encouraging initial results.

6.5 Summary

By revealing the inter-relationships between different data sources and methods, the general achievements of this research have been shown in monitoring changes in land use/land cover. Landsat imagery affords a means of establishing patterns of land use/land cover as well as monitoring and measuring its dynamics. The integration between remote sensing and GIS allows further exploitation of the potential of each. However, a combination of different data sources is required for an integrated study of land use. The different data sources and methods complement each other in obtaining satisfactory results from viewpoints of time, space, level of details and type of information.

Comparisons with previous studies in land use are made for further appraisal of the approach. Characterised by its integration of data and methods, this study has exemplified a way forward to demonstrate both the spatial distribution of land use within a region and the corresponding aspatial attribute information. Then limitations in using various data and difficulties identified in the study are put forward, error propagation in the change detection exercises and its analysis are also dealt with, along with suggestions for future developments by recognition of the research needs and trends.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

A feasible approach has been established for constructing patterns of regional land use/land cover and detecting its dynamics. The major objectives have thus been achieved on the basis of the selected study in South-East Scotland.

1). Integrated classification and mapping of land use/land cover have been carried out using Landsat images with the incorporation of other ancillary data through GIS.

2). The structure and trend of changes in land use/land cover in South-East Scotland during the past four decades have been described, mainly through the analysis of agricultural statistics and Landsat images.

3). The analysis of the parish summaries and detection of changes by post-classification comparison of Landsat images have shown the benefits of the effective synergism between remote sensing and GIS.

4). A combination of different data sources, methods and techniques is essential for an integrated study of regional land use. Although they can work independently to a certain extent, they complement each other to reveal changes in land use with different levels of details for the required period of time.

Some conclusions are drawn with regard to the significance of the analysis, to limitations identified in the study and to the foreseeable further work which is now appropriate.

The analysis and mapping of agricultural statistics at parish level have revealed the general characteristics of land use in the Lammermuir Hills area for the period from 1947 to 1987. The changing patterns of land use revealed are a continuation of previous studies' findings in that the basic land use zones have been shown to change from sheep farming on rough grazing land on top of the Hills to cropping and livestock raising on the higher ground bordering the Hills and then to intensive lowland arable farming. Certain trends of changes in land use have also been recognised. The importance of arable farming has been increasing and the upper limit of cultivation has expanded towards the upland whereas areas of grassland and rough grazing have been declining. Reflecting widespread afforestation, areas of woodlands on farms have increased through time. Whilst the limitations of the statistical data should be recognised, their substantial value for a long term retrospective study of regional land use has been examined and well appraised in this study. Most relevant information has been effectively and efficiently extracted from this historic data source through its cartographic representation, quantitative, temporal and correlation analyses, along with the application of computer-assisted systems. The usefulness of the data is evident. However, limitations of the data should be handled with caution in order to ensure the quality of analysis.

Landsat digital imagery affords an effective means of monitoring changes in land use/land cover. The analysis of Landsat images for two dates (24 April 1984 and 14 September 1986) is the principal thrust in this study and has demonstrated the potential and the acceptance of using such data in area measurement and mapping spatial distribution of land cover types. Major types of land use/land cover have been identified with adequate overall accuracy (88% for the TM image and 82% for the MSS image) by going through the procedure of geometric correction, training area definition and progressive refinement of the training signatures, segmentation of images, classification of the resulting signatures using the maximum likelihood classifier on different segments with different sets of statistics, and application of post-classification majority mode filter. Furthermore, the synergism of remote sensing and GIS has proved advantageous for achieving results with adequate accuracies of an integrated classification of land use/land cover. GIS provides ancillary data required by image analysis whilst remote sensing updates thematic overlay in GIS to maintain the currency of information on regional land use. A detailed study for a selected parish and comparison between imagery analysis and the parish summaries can then be carried out. The realisation of the integration between the two technologies presents a way ahead for land use studies in conjunction with rapid developments and wider applications of computer-assisted systems and the pressing need to study global changes.

Above all, this study has emphasised the importance of the integration of different data sources, methods and techniques for a complete study of regional land use. These data sources and approaches work both in parallel and supplementarily. On their own, they can reveal different aspects of regional land use. Meanwhile, their findings complement each other to produce a complete picture of land use.

The results of this study are obtained mainly through the case study in South-East Scotland. However, the method adopted and the approach established can be applied elsewhere. Procedures of detecting changes in land use/land cover are needed and are being developed in many parts of the world. More and more efforts have been made to demonstrate and exploit the potential of remote sensing data in updating resource inventories. Although the application of remote sensing analysis is moving into an operational tool, incorporation of other data such as agricultural statistics is still critical for success of any regional land use study. Thus GIS is playing an increasingly important role in fulfilling the task of the integration of different data sources and methods involved for a specific study. Further applications of the proposed approach to more test locations have not been realised because of the time and cost limitations. But the wide extent of the applicability of the method in this study is evident provided that caution is taken with any concrete practice.

7.2 Recommendations

Land use study has an unfailing significance and will continue to be an important issue, especially under the growing pressure for and the increasing enthusiasm for the monitoring of global change and environment. In view of what has been achieved in this study, in relation to further developments and implementations of an operational use of remote sensing and GIS for land use study, some suggestions for future research in land use based upon identified research needs and trends are put forward as follows:

(1). Further potential of remote sensing and GIS can be exploited when the two technologies are more effectively integrated for an automated approach. This will also lead to a further step in data integration. Regarding the relationship between remote sensing and conventional data applications, remote sensing offers another effective means for land use study with the ability and capacity of modelling. But it is not very likely for one to replicate or replace another for a long time to come. Confronting the results of the fast development of technology, one possibility might be a mixture of all types of data drawn from all types of sensors in a future research content. Increased efficiency in GIS manipulation and image processing has become even more urgent.

(2). A multi-temporal analysis of Landsat imagery is essential to overcome problems of clouds and shadows and to achieve better accuracy of image classification. This is even more important for a pragmatic integrated classification of regional land use taking into consideration its seasonal change.

(3). Error assessment in GIS and remote sensing analysis should keep up with the increasing use of the two technologies to ensure user acceptance and data quality. Data validation and quality control are definitely needed steps in current research and will be widely practised in all future projects.

(4). The utilisation and involvement of an expert system approach in future land use studies should be given sufficient attention, which may be the essential pre-requisite leading to automation and faster processing.

(5). The above points will be enriched by further developments in remote sensing and GIS. Satellites of the 1990s lay particular emphasis on their operational considerations. Continuing the current Landsat series, Landsat 6 will have an Enhanced Thematic Mapper (ETM) incorporating the multispectral capabilities of the TM and an additional 15 m panchromatic (0.5-0.9 m) band. Also, the proposed SPOT 4 and 5 intend to introduce a number of enhancements including an additional 20 m resolution channel in the mid infrared (1.5-1.7 m) and replacement of the 10 m panchromatic mode by a sampling of the 0.61-0.68 m band at 10 m spatial intervals to ensure excellent geometric registration between the 10 m (panchromatic) and 20 m (multispectral) data. In addition, microwave satellites are coming to a new era (*e.g.* ERS-1), which bring some hope to resolving problems of cloud cover in Landsat imagery. In short, it will be possible to improve land cover classifications for routine monitoring changes in land use to a larger extent, along with developments and applications of the next generation of satellites.

APPENDIX 1

Example of the Questionnaire Sent to Farmers by the DAFS and Keys to the Parish Names and Items Returned as Used for Computer Extraction from the University of Edinburgh Data Library

Department of Agriculture and Fisheries for Scotland.

Agricultural and Horticultural Census 2nd June, 1986
NOTICE REQUIRING INFORMATION BY 16th June, 1986

The Department of Agriculture and F
Economics and Statistics Unit
Chesser House, 500 Gorgie Road, Ec

May, 1986

AGRICULTURE ACT 1947, SECTION 78 (AS AMENDED)

As the occupier of the land to which this form relates you must complete the form. The information you give should be as at except where otherwise stated. **The completed form must be returned to the department as soon as possible after 2nd Jun later than 16th June, 1986. Please use the enclosed, pre-paid envelope.**

The information you give on the return is strictly confidential and cannot be disclosed without your written consent except as spe 80 of the above Act and Section 12 of the European Communities Act, 1972.

Anyone who fails to fill in and return the form or knowingly supplies false information may be prosecuted.

The area figures below are those previously received and **include** woods, roads, buildings, etc.

Total Area

Owned Area

OR PRESENT OCCUPIER

CHANGE OF ADDRESS/POST CODE

If your postal address is different from that above please give the correct address here:

....

....

.... Post Code ....

CHANGES IN AREA OF HOLDING

If the total area of your holding differs from that above the address, please give details. Exclude land rented for 364 days or less. Use a separate piece of paper if you need more space.

Land you have taken over

Name of land .... Code No. ....

Parish .... Area Acquired .... Hect.

Name and Address of Previous Occupier ....

Land you have given up

Name of land .... Code No. ....

Parish .... Area Given Up .... Hect.

Name and Address of Present Occupier ....

AGRICULTURAL AN
HORTICULTURAL RET
AS AT 2nd JUNE, 19

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METRIC CONVERSION TA

C.Q.	C.	FOR OFFICIAL US	
	A.		

SEASONAL USE OF L

If so many months of grazing for so many head of stc than a set area, please estimate the area used to sr let.

Area of land on this farm let seasonally (364 days or less), as at 2nd June, 1986 **to another person** for cropping or grazing. **(This land should be included elsewhere on the form as crops, grass or rough grazing).**	
Area of land **rented** seasonally, as at 2nd June, 1986 from **another person** for cropping or grazing. **(This land should NOT appear elsewhere on this form).**	

LAND RENTED AND/OR

Enter the total area of land to which this form relates yards and farm buildings), showing what area is agricultural tenancy and what area is owned by you near relative, a family trust or any business or conce interest, enter the area at item 10. Crofters should as rented. The **Total Area (Item 12) must agree** area and owned area should also agree with the fi unless you have taken over or given up land (accour left).

Rented by the occupier from an outside concern	
Rented from a near relative or from a concern in which the occupier has an interest	
Owned by the occupier	
TOTAL AREA OF LAN	

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CROPS

Enter the area, including headlands and ditches, of each crop at 2nd June, 1986. Land being prepared for a crop should be returned as under that crop.

Hectares (nearest 0.1)

Wheat		14	•
Barley	Winter	16	•
	Spring (including bere)	18	•
Oats		20	•
Mixed grain for threshing (only mixtures of wheat, barley, and oats or any two of these)		22	•
Rape for oilseed		23	•
Potatoes intended mainly for **SEED**		24	•
Potatoes intended mainly for **WARE**	Earlies intended for harvesting on or **by 31st July**	25	•
	Main crop intended for harvesting **after 31st July**	26	•
Peas for Combining		28	•
Turnips and swedes for stock feeding (**Not** for human consumption)		29	•
Kale and Cabbage for stock feeding (**Not** for human consumption)		30	•
Rape for Stockfeeding (**Not** oilseed rape)		31	•
Fodder Beet		32	•
Other Crops for Stock Feeding (**Not** grass)		34	•
Vegetables for Human Consumption grown in the open (must agree with item 68)		35	•
Orchard Fruit - apples, plums, etc., for sale or manufacture. Include land planted with maiden trees but exclude fruit stocks (see item 80).		36	•
Soft Fruit, (must agree with item 76)		37	•
Other Crops not included above (**Not** Grass) Include here **Glasshouse Crops**, Item 84, and areas of unspecified crops, including mixed crops (other than vegetables or soft fruit at 67 and 75), which are too small to be shown separately. (see also foot of column).		38	•
Bare Fallow—land left uncropped for the season.		39	•
TOTAL CROPS AND FALLOW		40	•

Item 38 (Other Crops). If crops other than glasshouse crops, bulbs, flowers and nursery stock are included, please enter the **total** area in the box below.

Hectares (nearest 0.1)

Unspecified Crops—total area	41	•

Please name any major unspecified crops, e.g., flax, 5 hectares, in the space below.

GRASSLAND

Land should be shown as "Grassland" where productive grasses, clovers, etc., are dominant. Land which cannot normally be cultivated or is dominated by poor quality grasses, heather, bracken, etc., should be returned as "Rough Grazings".

Hectares (nearest 0.1)

FOR MOWING this season	**Under 5 years old** (including grass sown this year without a nurse crop)	42	•
	5th year grass and older (i.e. sown in 1981 or earlier)	43	•
NOT FOR MOWING this season	**Under 5 years old** (including grass sown this year without a nurse crop)	44	•
	5th year grass and older (i.e. sown in 1981 or earlier)	45	•

TOTAL CROPS AND GRASS (total of item 40 and items 42 to 45)	46	•
Rough Grazings—Mountain, Hill, Moor, Deer Forest situated within the farming unit, whether enclosed or not. **Do not include** woods, roads, etc., a share in common grazing or any land taken by you for the season.	47	•
Woodlands—(other than commercial orchards)—situated within the farming unit for shelter belts, fencing materials, other farm uses and for commercial or amenity purposes.	48	•
Other Land i.e. roads, yards, buildings (excluding glasshouses), ponds, derelict land, etc.	49	•
TOTAL AREA OF ALL LAND **to which this form relates** (total of items 46 and 47 to 49; must also agree with item 12).	50	•

VEGETABLES FOR HUMAN CONSUMPTION GROWN IN THE OPEN

Do not give number of rows or plants. **Include** under the appropriate crop **land** prepared for it but **not yet planted.**

Hectares (nearest 0.1)

Peas for canning, freezing or drying (**Not** green peas for market or peas for stock feed).		52	•
Beans for canning, freezing or drying (**Not** fresh beans for market or beans for stock feed)		53	•
Leeks (include land prepared for the crop)		55	•
Turnips and Swedes for human consumption		56	•
Cabbages and Savoys for human consumption (include land prepared for the crop)	Summer/Autumn	57	•
	All other	58	•
Brussels Sprouts (include land prepared for the crop)		59	•
Calabrese Broccoli		60	•
Cauliflower and Broccoli-Heading Varieties (include land prepared for the crop)		61	•
Carrots		63	•
Lettuce		64	•
Rhubarb		65	•
Other Vegetables grown in the open (**Not** tomatoes or other glasshouse crops)		66	•
Mixed Vegetables—areas which as individual crops are too small to be shown separately		67	•
TOTAL VEGETABLES must agree with item 35)		68	•

Please see over

SOFT FRUIT

Exclude spawn beds, runner beds and young plants intended for sale. (These should be entered at item 80).

		Hectares (nearest 0.1)
Strawberries	70	•
Raspberries	71	•
Blackcurrants	72	•
Mixed and Other Kinds of soft fruit including the areas of soft fruits named above which as individual crops are too small to be shown separately.	75	•
TOTAL SOFT FRUIT (must agree with item 37)	76	•

BULBS, FLOWERS AND NURSERY STOCK GROWN IN THE OPEN

Do not give number of plants.

			Hectares (nearest 0.1)
Bulbs grown for the production of dry bulbs and/or cut flowers **in the open**		77	•
Other flowers for cutting **in the open** not from bulbs including land prepared for the crop		78	•
Hardy Nursery Stock	**Fruit Stocks**—spawn beds, runner beds and stool beds and young plants intended for sale	80	•
	Roses and Rose Stocks	81	•
	Ornamental trees and shrubs (not forest trees)	82	•
	Other nursery stock (herbaceous plants, alpines, etc.)	83	•
TOTAL (include also in item 38)		84	•

GLASSHOUSES AND TOMATOES

See metric conversion tables.

			sq. metres
GLASSHOUSES in use	"Walk-in" Plastic Structures	85	
	Glass clad structures	86	
	Tomatoes	87	

Include total area of glasshouse crops in item 38.

HAY, STRAW AND SILAGE STOCKS

Include stocks left over from previous seasons and any which have been bought in.

		Tonnes (nearest tonne)
Hay, on holding at 2nd June, 1986 (Tonnes)	91	
Straw, on holding at 2nd June, 1986 (Tonnes)	92	
Silage, on holding at 2nd June, 1986 (Tonnes)	93	

LIVESTOCK

Enter livestock belonging or hired to you (or to your workers or family, unless these persons make an agricultural return in their own right), **whether on your farm or elsewhere. Include livestock** you are keeping and managing **on contract** for someone else. Enter livestock sent for sale on 30th May or 2nd June.

Exclude any of your **livestock kept on contract for you** by another farmer or **on hire to another farmer** and any **livestock** owned by another farmer which are **temporarily on your farm** but which you are not managing on contract.

HORSES

		Number
Horses used for agricultural or horticultural purposes	95	
All other Horses and Ponies	96	

GOATS

Goats of all ages	98	

CATTL

Cows and Heifers in milk			**Dairy**	
			Beef	
Cows in Calf but not in milk			**Dairy**	
			Beef	
Heifers in Calf for the first time			2 years old and over	
			Under 2 years old	
Bulls for Service			2 years old and over	
			1 year old and under	
All Other Cattle	2 years old and over		**Male**	
		Female	for **Breeding**	
			Not for br	
	1 year old and under 2		**Male**	
		Female	for **Breeding**	
			Not for br	
	6 months old and under 1 year			
	Under 6 months old			
TOTAL C				

CALVES SOLD AND B THE LAST

Enter the **number** of calves (i.e. under 1 yea last year.

Calves Sold between 1st June 1985 and 2nd June 1986	**Under 6 month** including calves immediate slaug	
	6 months old ar 1 year	
Calves Bought between 1st June 1985 and 2nd June 1986	**Under 6 month** at time of purch	
	6 months old ar 1 year at time o	

IRISH CATTLE

Cattle you bought directly, or almost directly, from the Irish Republic or Northern Ireland during the **year** from 1st June, 1985 to 2nd June, 1986	for Br	
	for Fe	

164

Number

URING

bought during the

Number

Number

SHEEP

Do not enter your share in a Sheep Stock Club as the Club Secretary will return these sheep.

Enter at question 139 only those **Ewes and Gimmers which have survived** until 2nd June and still belong to you.

			Number
Ewes used for breeding in 1985/86 season (Actual Number at 2nd June, 1986.)		139	
Rams to be used for service in 1986		140	
Other Sheep 1 year old and over	For breeding	141	
	Other	143	
Other Sheep under 1 year old (inc. **Lambs**)		144	
	TOTAL SHEEP	145	

PIGS

Enter pigs being kept **under contract** on your farm.

			Number
Sows in Pig		146	
Gilts in Pig		147	
Other Sows for breeding		148	
Barren Sows for fattening		149	
Gilts 50Kg (110 lb) and over, not yet in pig, but **expected to be used for breeding**		150	
Boars being used for service		151	
All Other Pigs (not entered above)	110Kg (240lb) liveweight and over	152	
	80Kg (175lb) and under 110Kg (240lb) liveweight	153	
	50Kg (110lb) and under 80Kg (175lb) liveweight	154	
	20Kg (45lb) and under 50Kg (110lb) liveweight	155	
	under 20Kg (45lb) liveweight	156	
	TOTAL PIGS	157	

POULTRY

Exclude game birds.

Enter poultry being kept **under contract** on your farm.

				Number
Fowls for producing eggs for eating	**Pullets** and **Hens** in the laying flock	**Pullets—fowls** in first laying season	158	
		Hens—other fowls including those in moult	159	
	Growing pullets—day old to point of lay		161	
Fowls for breeding	**Pullets and Hens** of all ages kept (or being reared) mainly for producing hatching eggs		162	
	Cocks of all ages kept (or being reared) for breeding		163	
Fowls being reared for the table—**broilers and other table birds including table cockerels**			164	
Other Poultry (ducks, geese, guinea fowl)			167	
Turkeys of all ages—including breeding stock			169	
	TOTAL POULTRY		170	

OTHER HOLDINGS IN THE SAME OCCUPANCY

Please give the Code No.'s under which you, your Company or Partnership make agricultural census returns for other holdings.	172	
	173	
	174	
	175	
	176	
If Code Nos. not known enter addresses here:		

LABOUR
OCCUPIER AND WIFE OR HUSBAND

If you are doing farm work (including office work) enter yourself in this section, also your wife/husband if she/he is doing farm work.

Enter yourself as part-time if you work less than about 40 hours per week on the farm, even if you have no other job. If you have more than one farm, do not enter yourself and your spouse on more than one return.

When the farm is run by a partnership or company, enter only the principal or senior working partner or director as the occupier, enter also the spouse, if doing farm work.

Include other working partners or directors in the "All Other Labour" section.

				Number
Occupier—if doing farm work (**one person only**).	Full-time		177	
	Part-time	(**More** than ½ time)	178	
		(**Less** than ½ time)	179	
Wife/Husband of occupier (if doing farm work)			181	

ALL OTHER LABOUR EXCLUDING OCCUPIER, WIFE OR HUSBAND ENTERED ABOVE

This section relates only to persons working for you on 2nd June, including those that were sick or on holiday on that day.

Exclude anyone working under THE YOUTH TRAINING SCHEME.

Leave out school children, non-farm workers working on buildings, installing plant or carrying out contract work, and gardeners or estate workers who do no farm work.

Enter once only, and on only one return, all persons doing farm work including drainage, ditching, maintenance and repair work and transport of farm goods.

Part-time workers are those who do farm work **each week** but for **less** than the full working week.

Casual and seasonal workers are those actually working on 2nd June doing work of a temporary or seasonal nature; include labour supplied by gangmasters.

				Number
FULL-TIME REGULAR STAFF employed on 2nd June	**Males**—20 years old and over	Hired	188	
		Members of Occupier's family	189	
	Males—under 20 years old	Hired	190	
		Members of Occupier's family	191	
	Women and Girls	Hired	192	
		Members of Occupier's family	193	
PART-TIME REGULAR STAFF employed on 2nd June	**Males**	Hired	194	
		Members of Occupier's family	195	
	Women and Girls	Hired	196	
		Members of Occupier's family	197	
Casual and Seasonal Workers Employed on 2nd June		Males	198	
		Women and Girls	199	
TOTAL REGULAR AND CASUAL STAFF (excluding entries of occupier and spouse)			200	

I declare the information I have given on this form to be correct to the best of my knowledge and belief.

SIGNATURE OF OCCUPIER ....

Date .... Telephone No. ....

If signature is not that of the addressee, please say why, e.g., "manager", "new owner", "occupier abroad" etc.

FOR OFFICIAL USE			
Q.	D.	Ex.	D. 165

Key to the Parish Names

Abbey St. Bathans	242
Aberlady	365
Athelstaneford	357
Ayton and Eyemouth	243
Bolton	358
Bunkle and Preston	244
Channelkirk	265
Chirnside	245
Cockburnspath	246
Coldingham	247
Coldstream	252
Cranshaws	253
Cranston and Crichton	564
Crichton	565
Dirleton	366
Dunbar	350
Duns and Cranshaws	254
Earlston	266
Eccles	255
Edrom and Fogo	256
Eyemouth	248
Fala and Soutra	566
Fogo	257
Foulden	249
Garvald	359
Gladsmuir	370
Gordon	267
Greenlaw	258
Haddington	360
Heriot	567
Humbie	361
Hume	268
Hutton	250
Innerwick	351
Ladykirk	259
Langformacus	261
Langton and Polwarth	260
Lauder	269
Legerwood	270
Mertoun	271
Mordington	251
Morham	362
Nenthorn	272

Data Cell Codes and Item Names for Different Years

1947 (acre):

904	Total Crops and Fallow
880	Total crops and Grass
81	Rough Grazing
45, 46	Wheat
47	Barley
48	Oats
49	Mixed Grain
55, 56	Potatoes for Ware
33, 57	Turnips and Swedes
938	Cattle
940	Sheep
906	Total land

1950 (acre):

68a	Total Crops and Fallow
880	Total Crops and Grass
74	Rough Grazing
44, 45	Wheat
46	Barley
47	Oats
48	Mixed Grain
53,54	Potatoes for Ware
25,55	Turnips and Swedes
938	Cattle
940	Sheep
904	Crops and Grass and Rough Grazing

1955 (acre):

	Total Crops and Fallows
	Total Crops and Grass
	Rough Grazing
	Wheat
	Barley
	Oats
	Mixed Grain
8,9	Potatoes for Ware
10,39	Turnips and Swedes
	Total Cattle
	Total Sheep

1960 (acre):

	Total Crops and Fallow
	Total Crops and Grass
	Rough Grazing
	Woodlands
	Wheat
	Barley
	Oats
	Mixed Grain
8,9	Potatoes for Ware
10,48	Turnips and Swedes
	Cattle
	Sheep
	Total Land

1965 (acre):

	Total crops and Fallow
	Total Crops and Grass
	Rough Grazing
	Woodland
	Wheat
	Barley
	Oats
	Mixed Grain
8,9	Potatoes for Ware
10,51	Turnips and Swedes
	Dairy Cattle
	Beef Cattle
	Sheep
	Total Land

1969-72 (in 1/4 acres):

20	Total Crops and Fallow
32	Total Crops and Grass
34	Rough Grazing
35	Woodlands on Farm
4	Wheat
5	Barley
6	Oats
7	Mixed Grain
8	Potatoes for Seed
21,22	Potatoes for Ware

10	Turnips and Swedes
133	Total Dairy Cattle
134	Total Beef Cattle
135	Total Sheep
37	Total Area of Land
145	Land Gained from Forestry Commission
157	Land Lost to Forestry Commission
163	Total average of holdings

<u>1976-81 (hectare):</u>

20	Total Crops and Fallow
32	Total Crops and Grass
34	Rough Grazing
35	Woodlands
4	Wheat
5	Barley
6	Oats
7	Mixed Grain
8	Potatoes for Seed
21,22	Potatoes for Ware
10	Turnips and Swedes
134	Total Cattle
135	Total Sheep
37	Total Land

<u>1984 (hectare):</u>

40	Total Crops and Fallow
46	Total Crops and Grass
47	Rough Grazing
48	Woodland
14	Wheat
17	Barley
20	Oats
22	Mixed Grain
23	Oilseed Rape
24	Potatoes for Seed
25,26	Potatoes for Ware
29	Turnips and Swedes
122	Total Cattle
145	Total Sheep
50	Total Land

1985-86 (hectare):

40	Total Crops and Fallow
46	Total Crops and Grass
47	Rough Grazing
48	Woodland
14	Wheat
16	Winter Barley
18	Spring Barley
20	Oats
22	Mixed Grain
23	Oilseed Rape
24	Potatoes for Seed
25,26	Potatoes for ware
29	Turnips and Swedes
122	Total Cattle
145	Total Sheep
50	Total Land

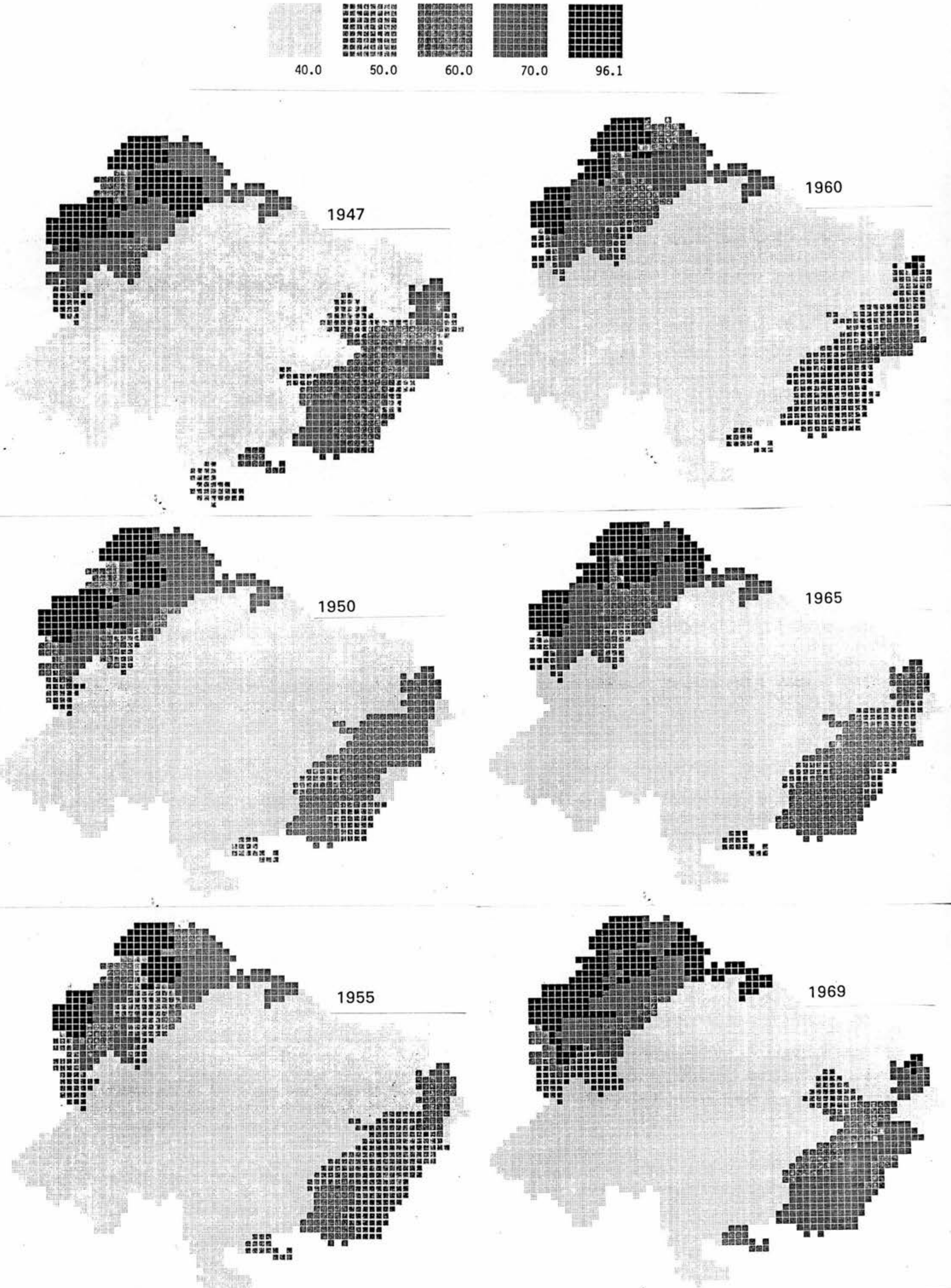
1987 (hectare):

40	Total Crops and Fallow
46	Total Crops and Grass
47	Rough Grazing
48	Woodland
14	Wheat
16	Winter Barley
18	Spring Barley
20	Oats
22	Mixed Grain
23	Oilseed Rape
24	Potatoes for Seed
25,26	Potatoes for ware
29	Turnips and Swedes
122	Total Cattle
145	Total Sheep
50	Total Land
224-239	Farm Types

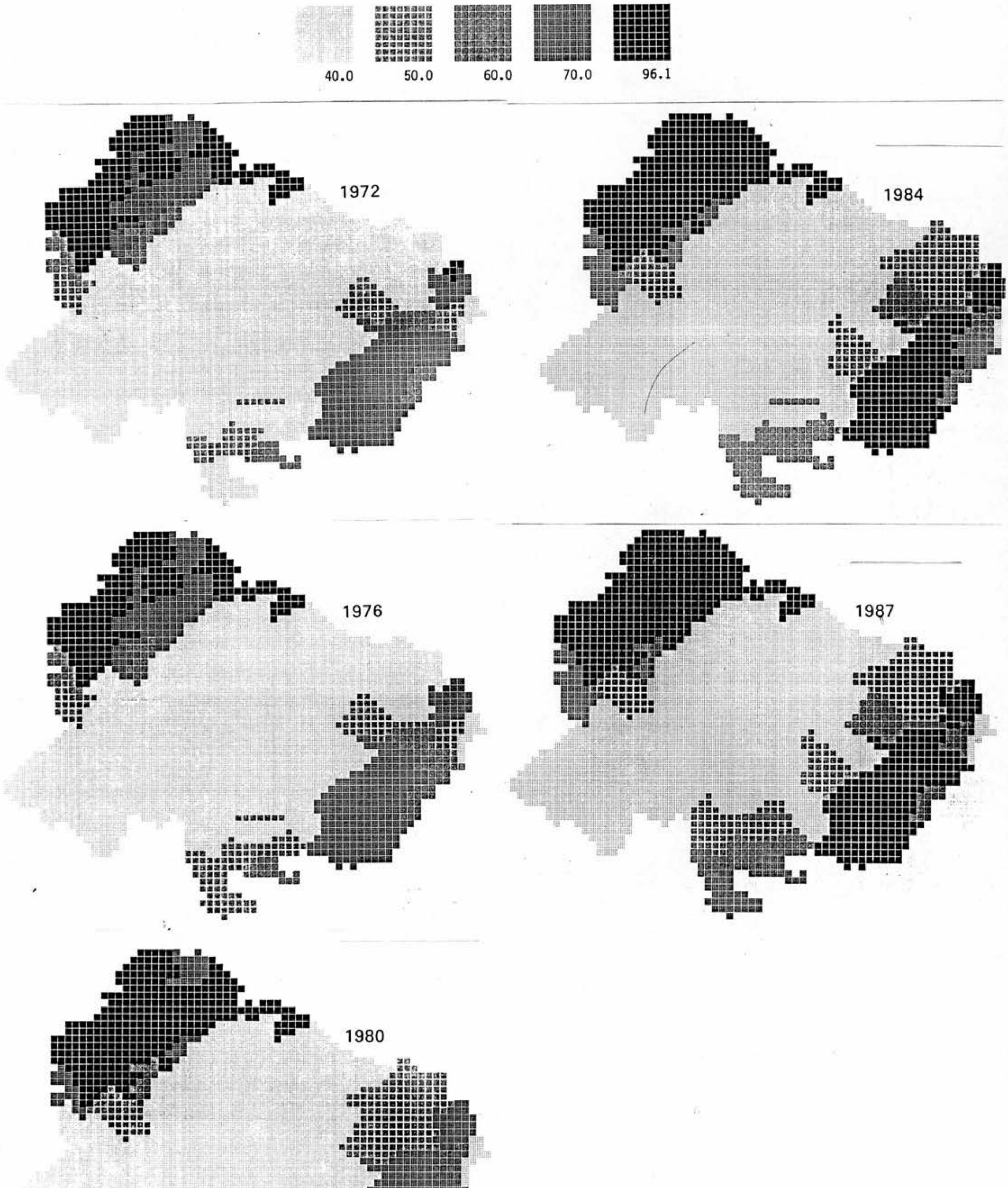
APPENDIX 2

Map Series from CAMAPGB1

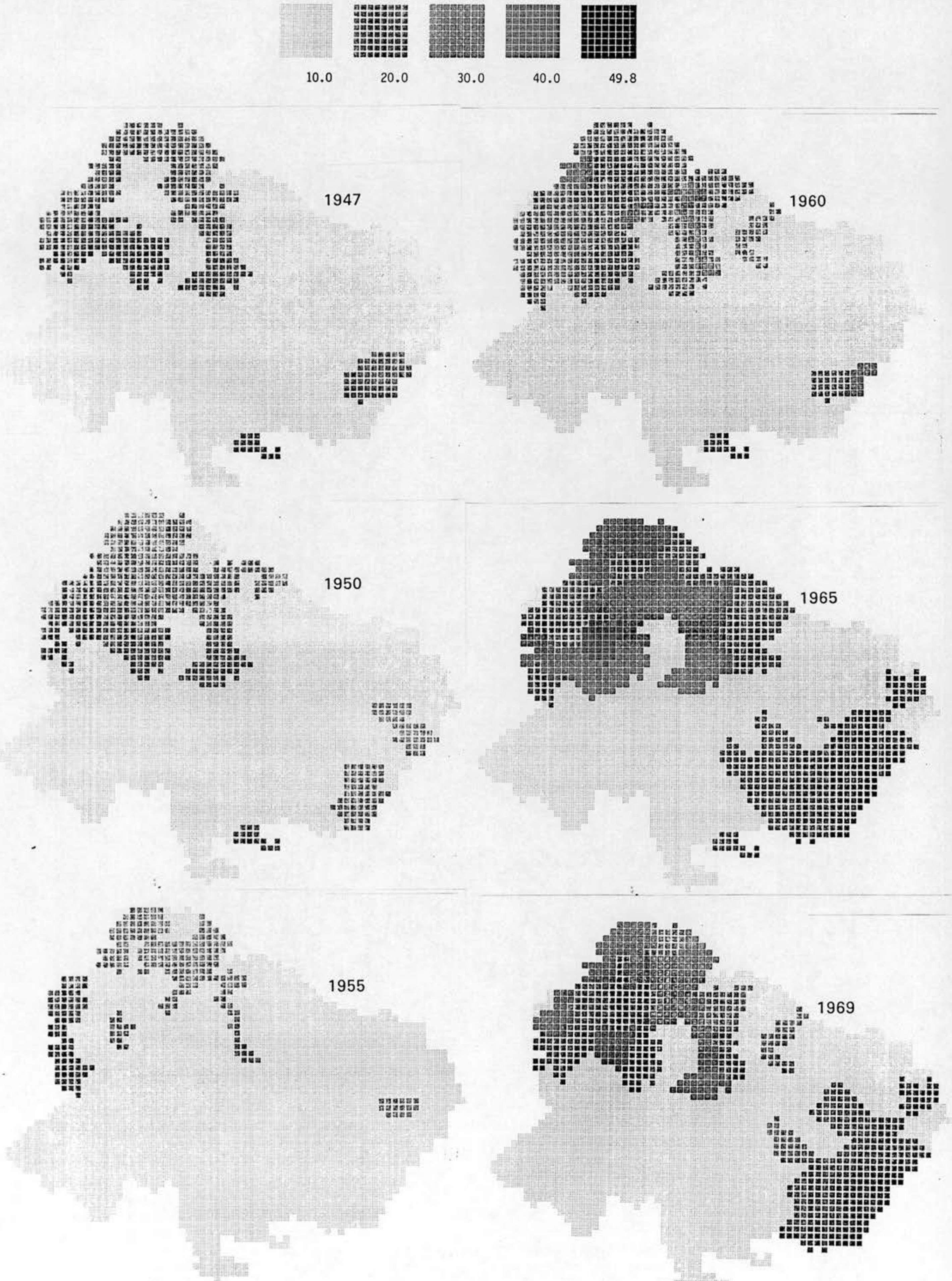
Crops & Fallow for Every 100 Hectares of Agricultural Land



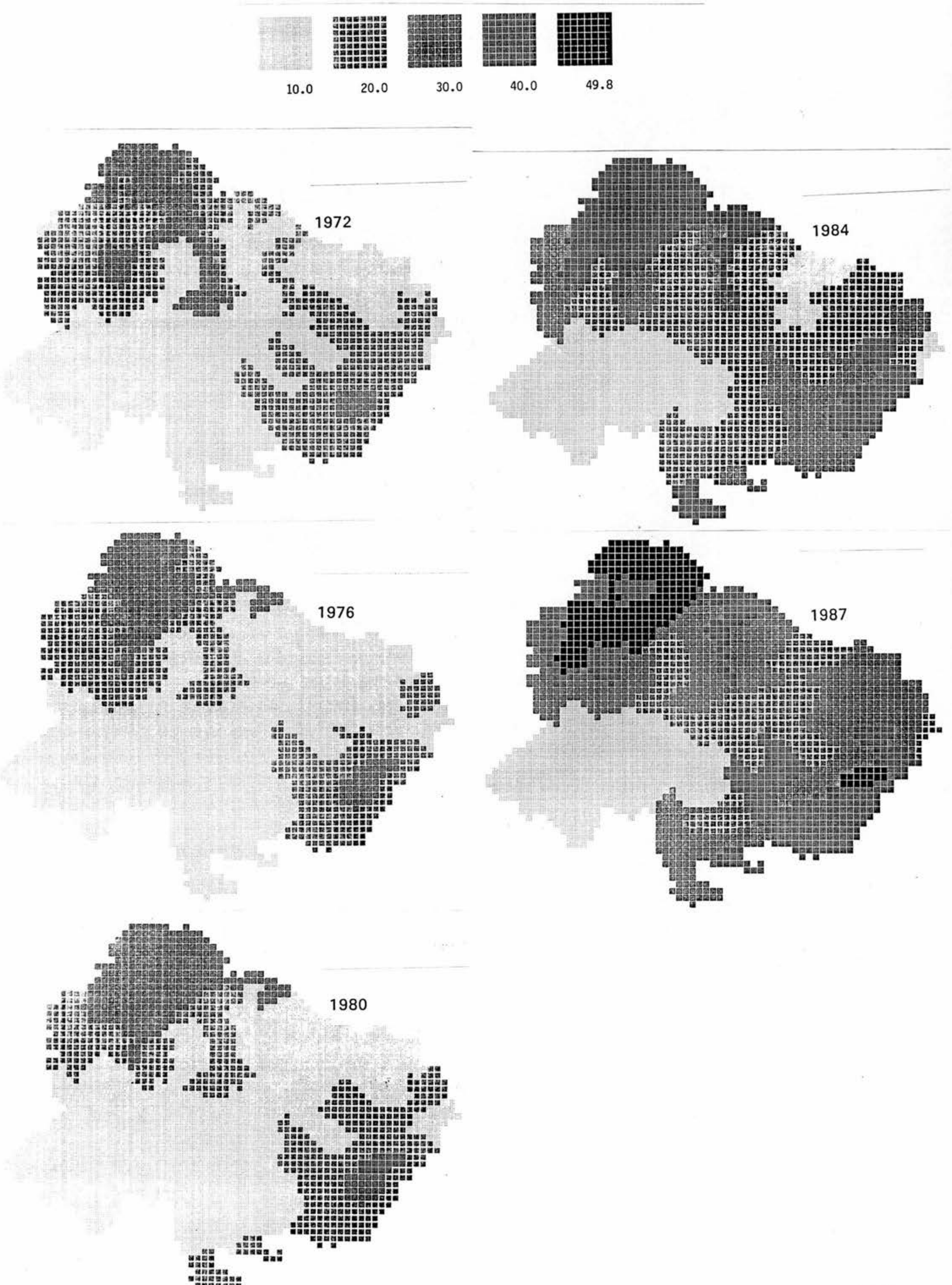
Crops & Fallow for Every 100 Hectares of Agricultural Land



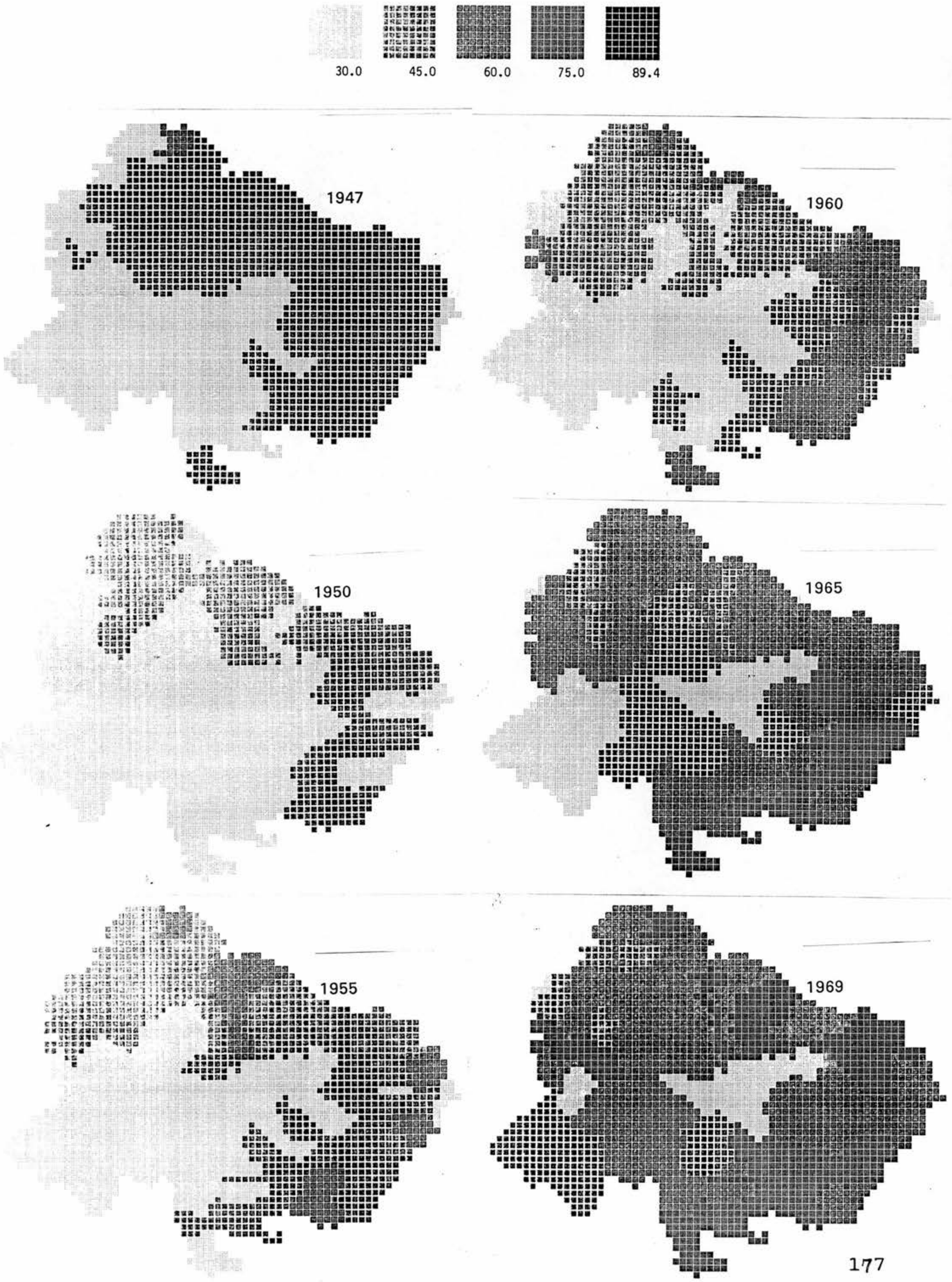
Wheat Area for Every 100 Hectares of Tillage



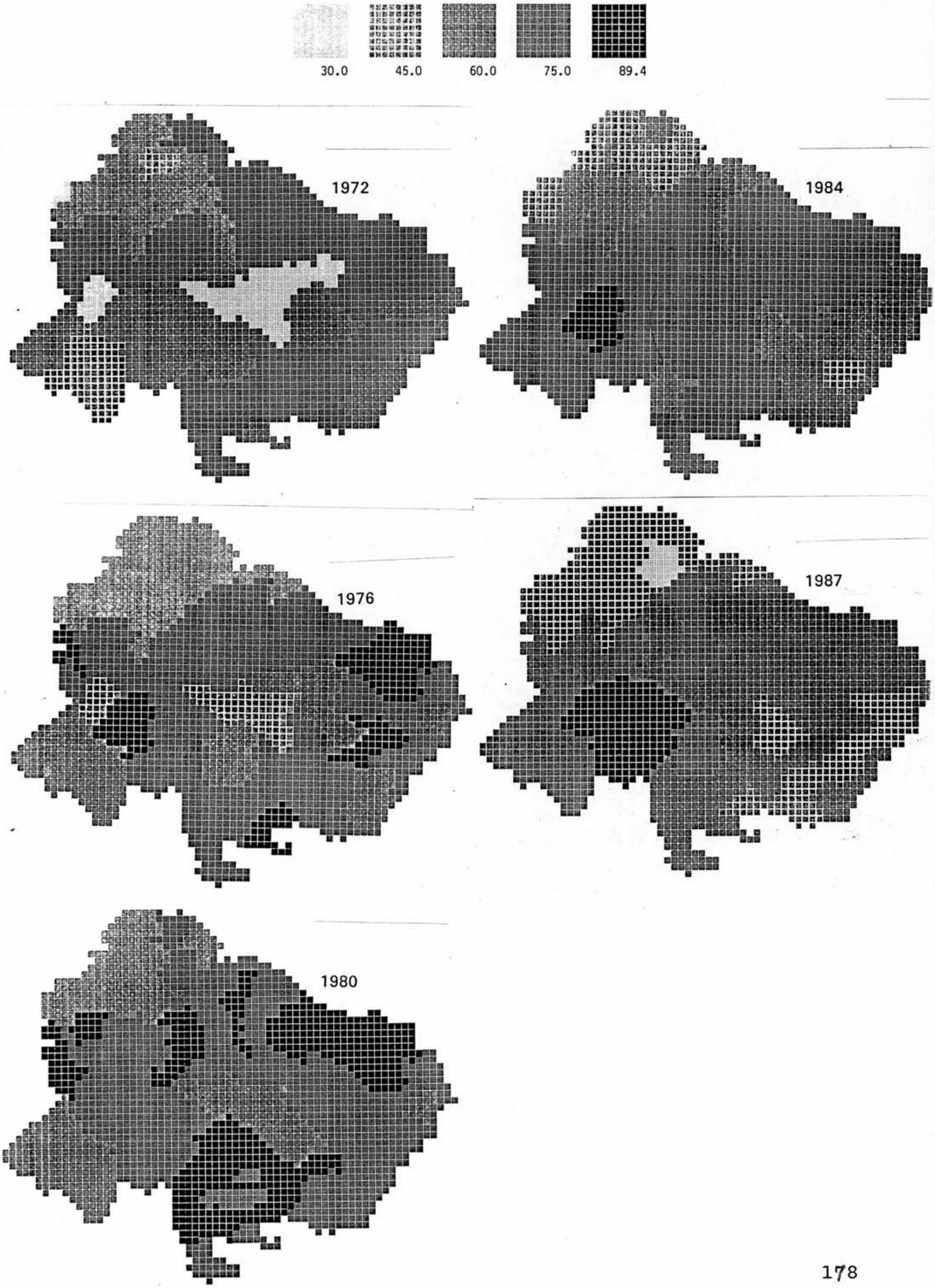
Wheat Area for Every 100 Hectares of Tillage



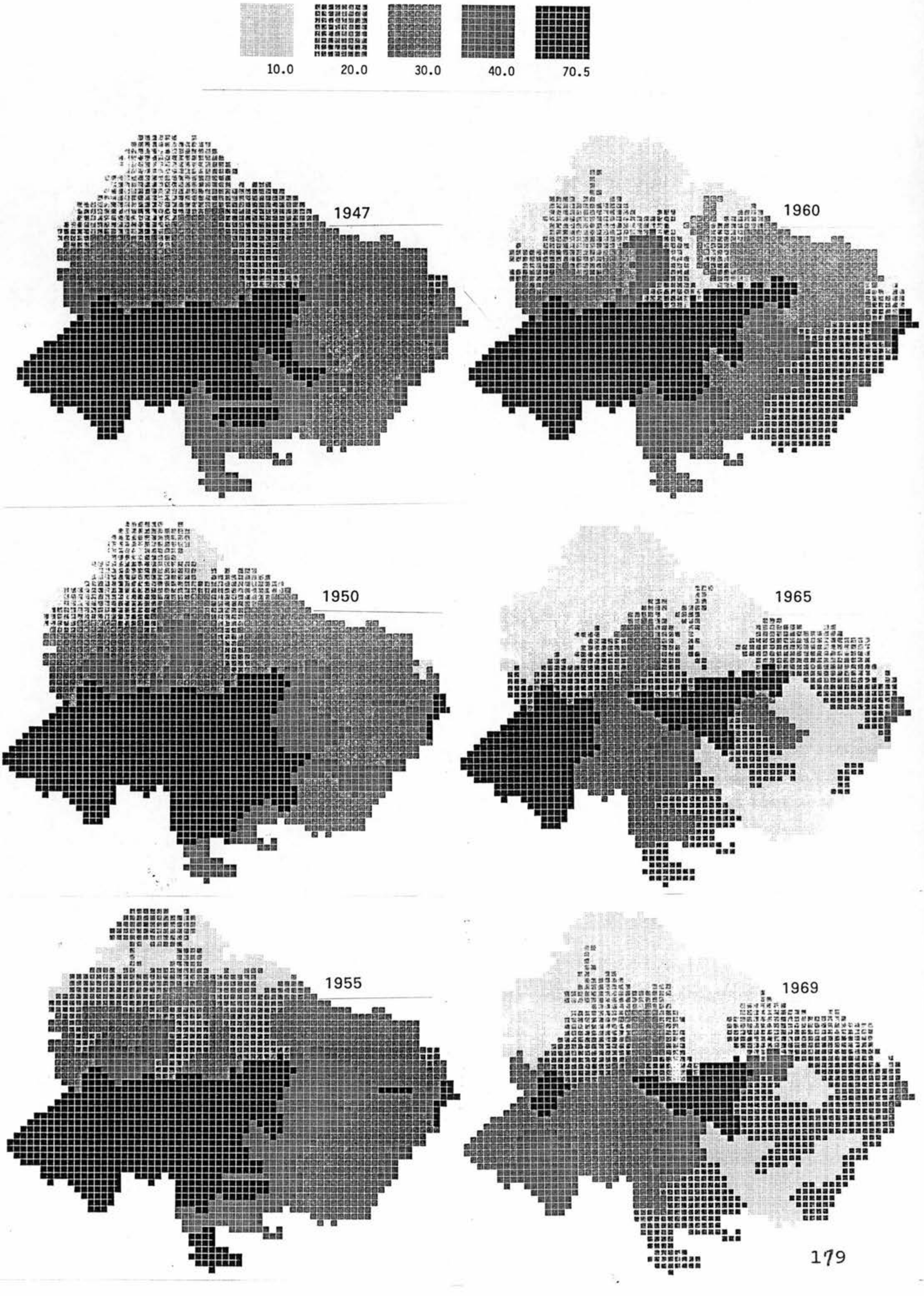
Barley Area for Every 100 Hectares of Tillage



Barley Area for Every 100 Hectares of Tillage

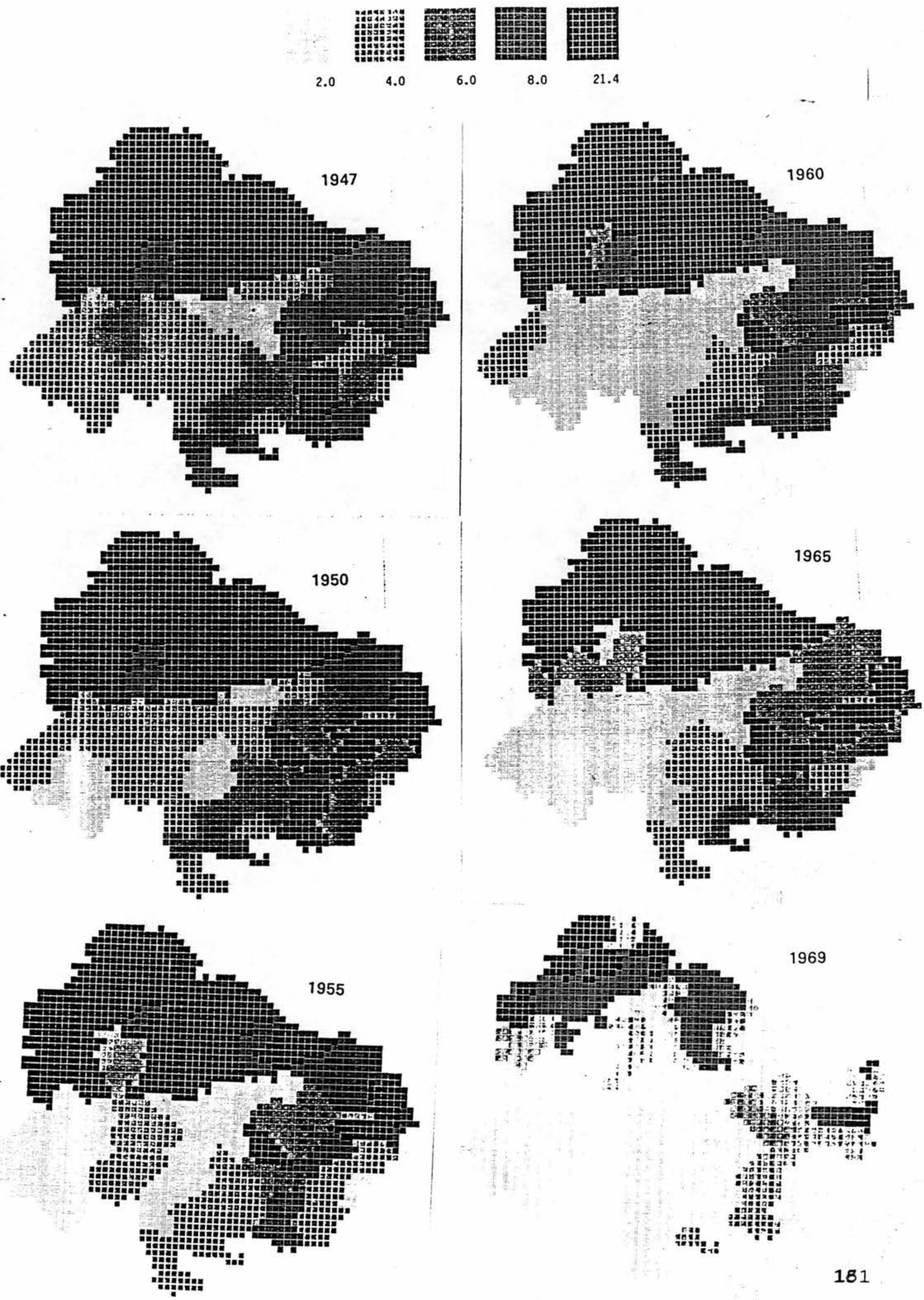


Oats Area for Every 100 Hectares of Tillage

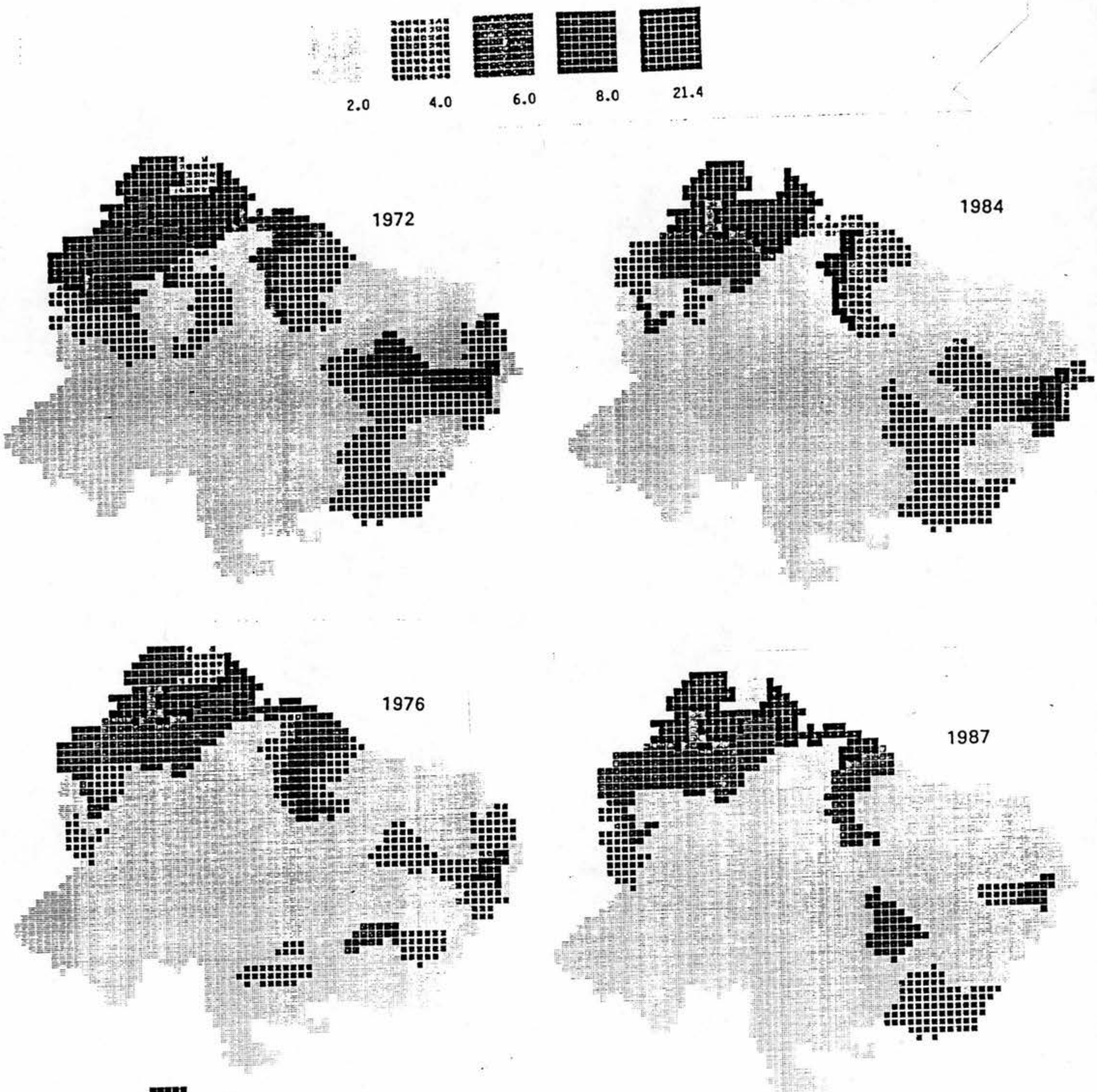


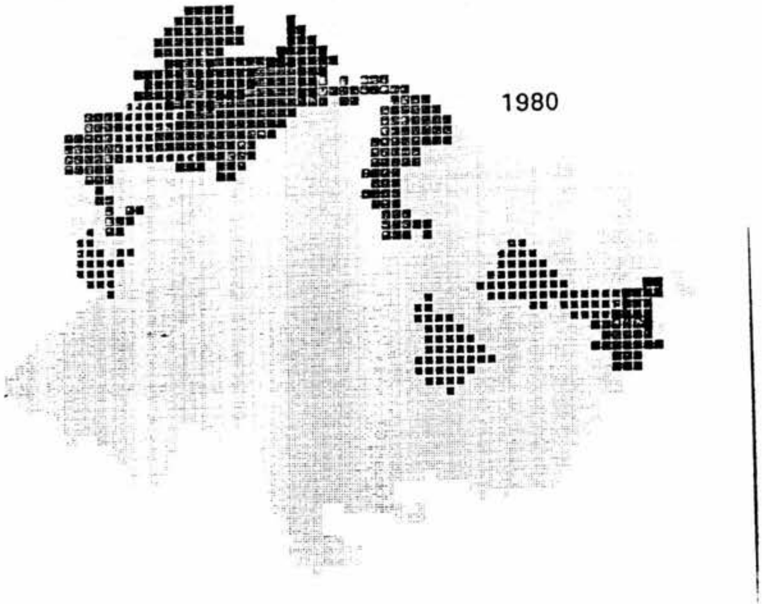
Oats Area for Every 100 Hectares of Tillage

Land under Potatoes for Ware for Every 100 Hectares of Tillage

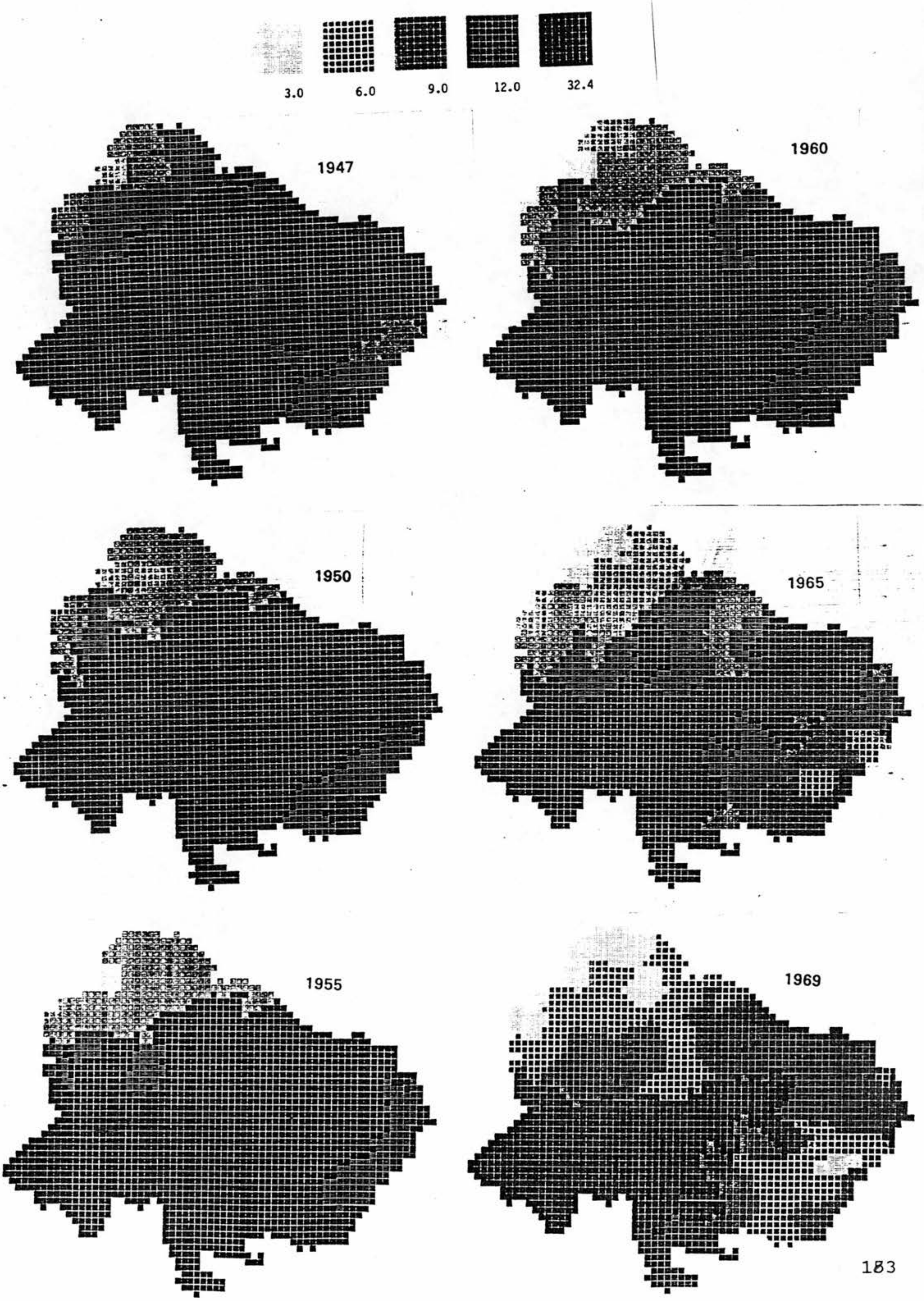


Land under Potatoes for Ware for Every 100 Hectares of Tillage

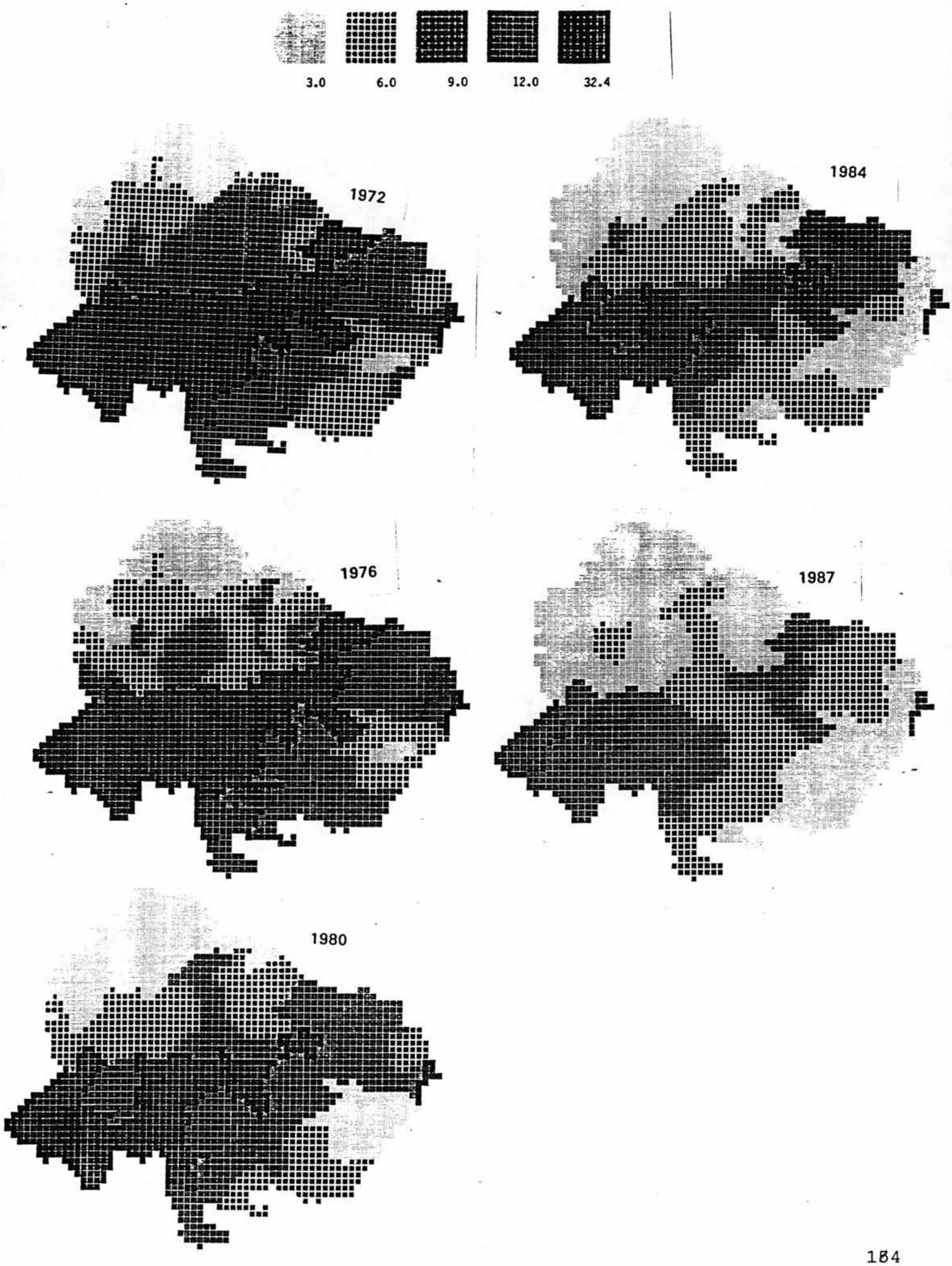




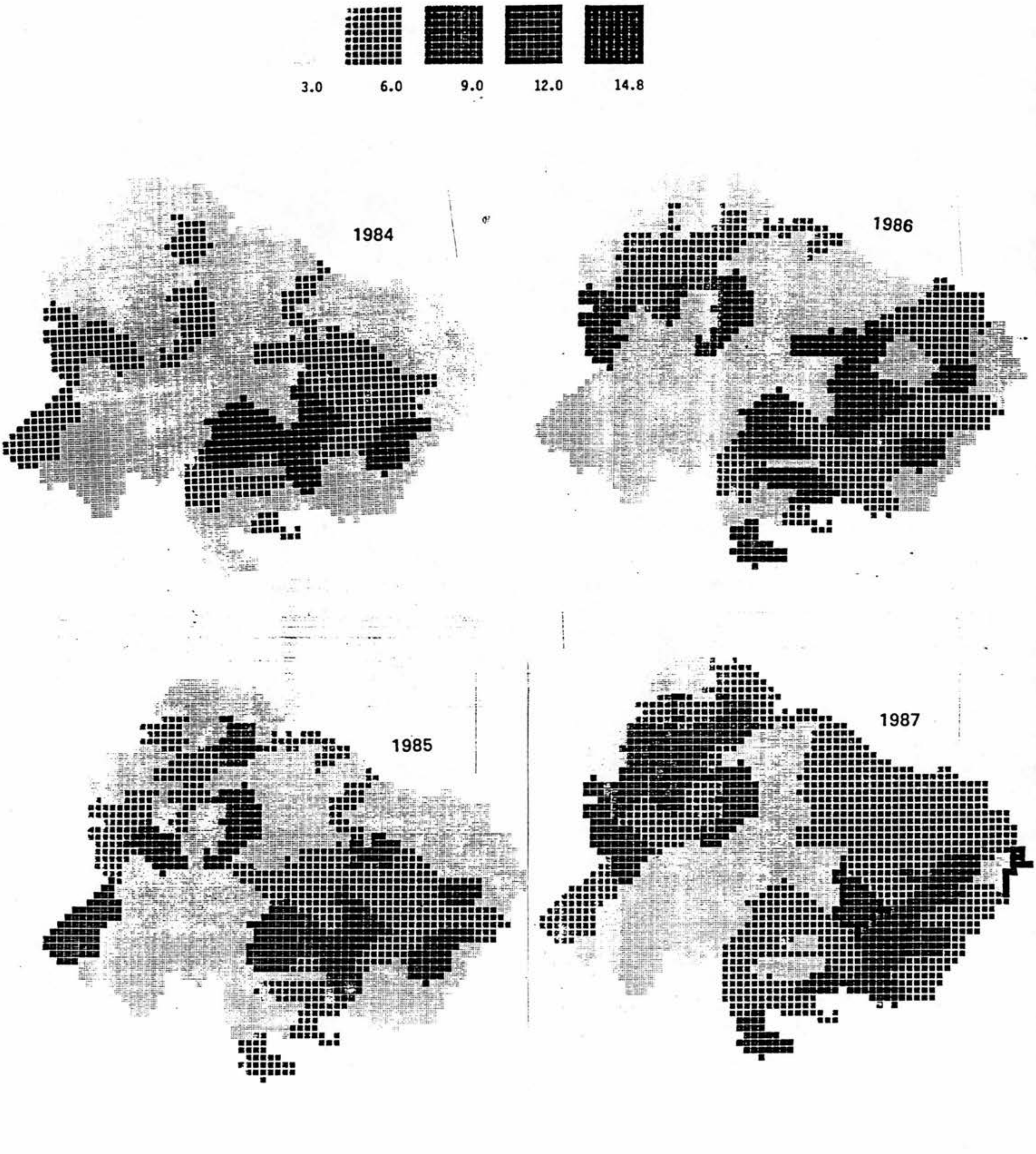
Land under Turnips & Swedes for Every 100 Hectares of Tillage



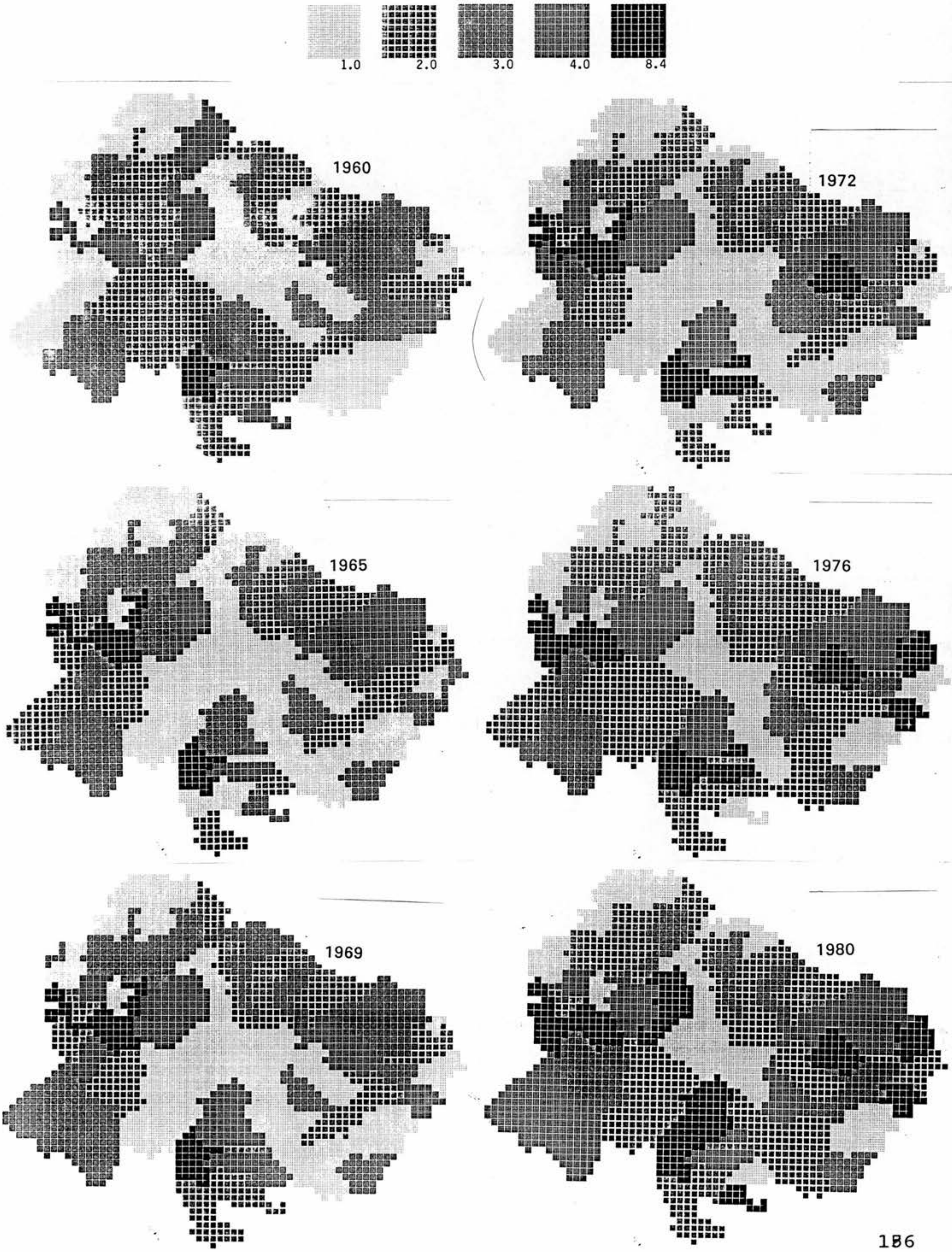
Land under Turnips & Swedes for Every 100 Hectares of Tillage



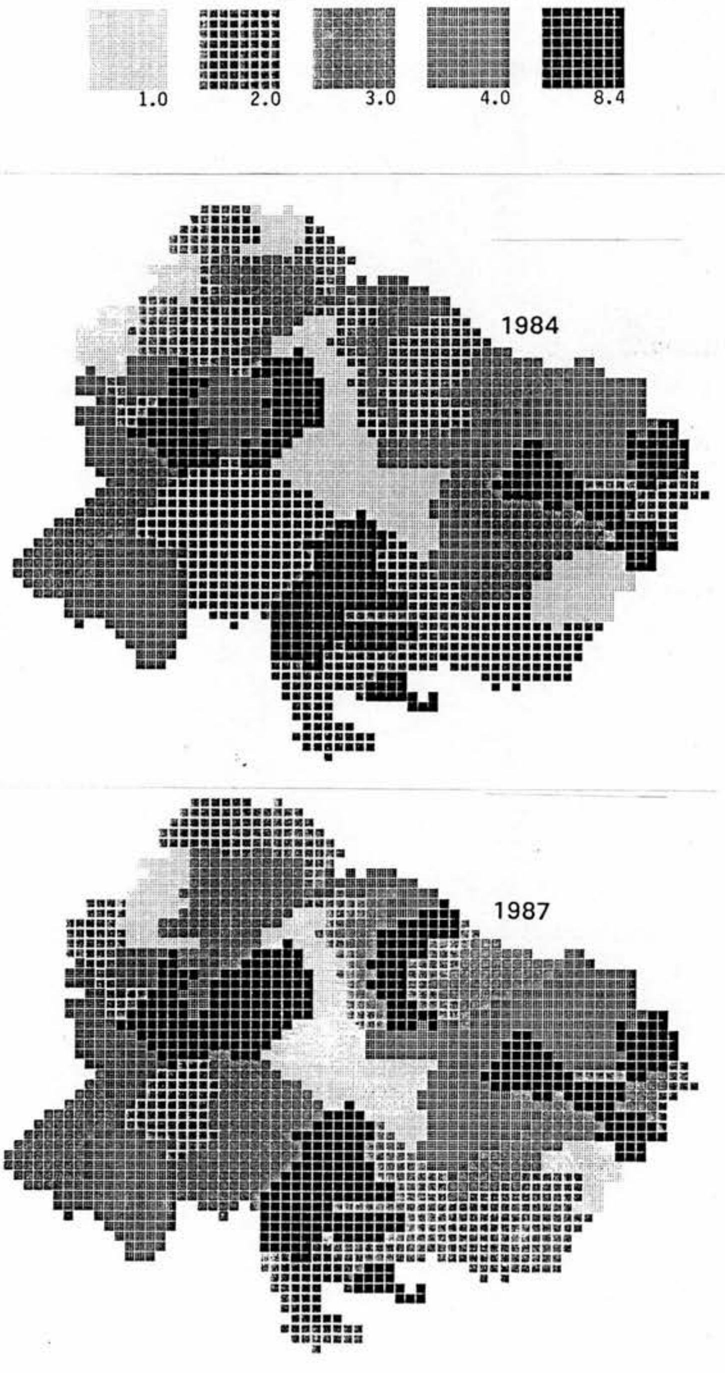
Land under Oilseed Rape for Every 100 Hectares of Tillage



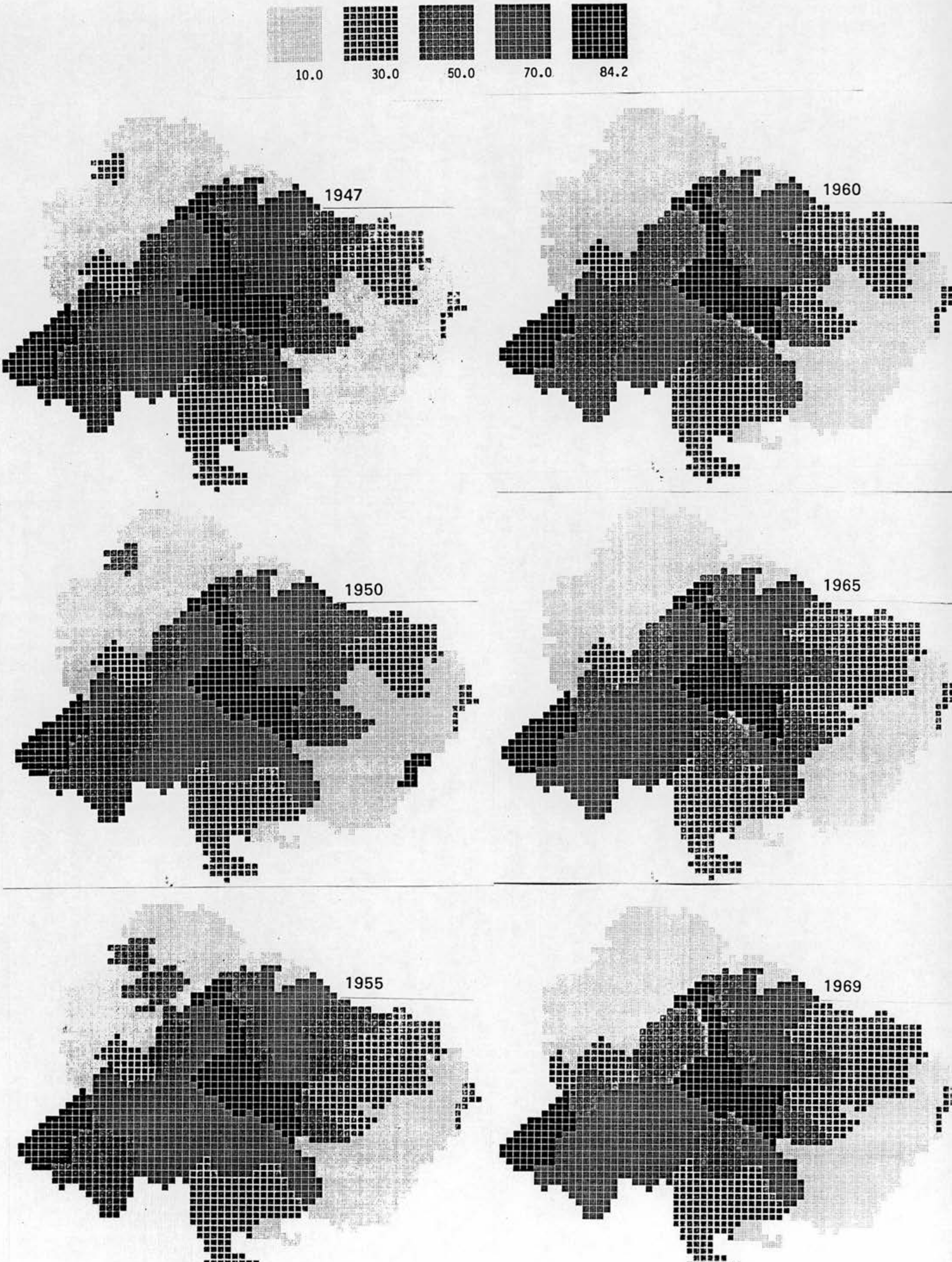
Farm Woodland for Every 100 Hectares of Agricultural Land



Farm Woodland for Every 100 Hectares of Agricultural Land

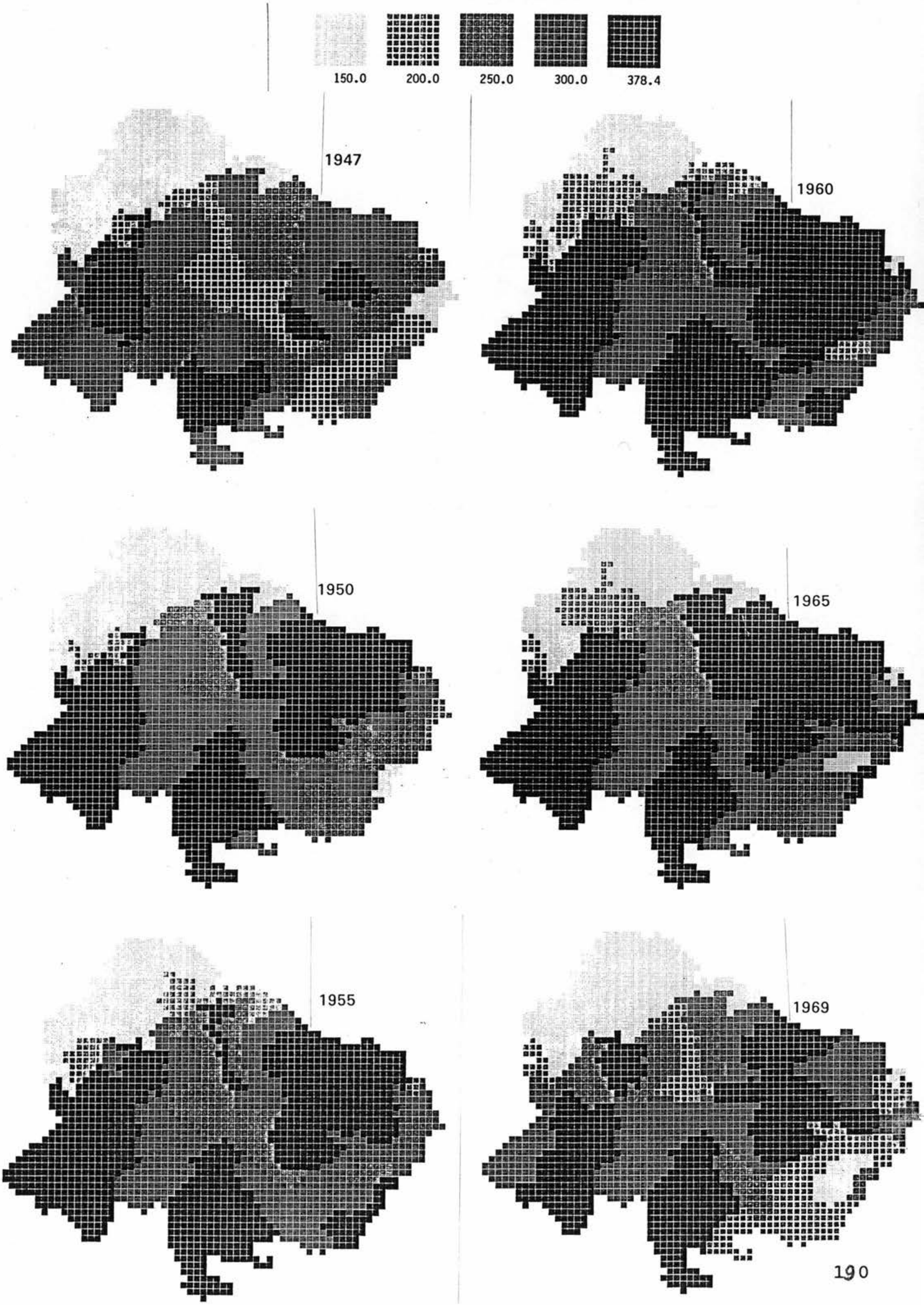


Rough Grazing for Every 100 Hectares of Agricultural Land

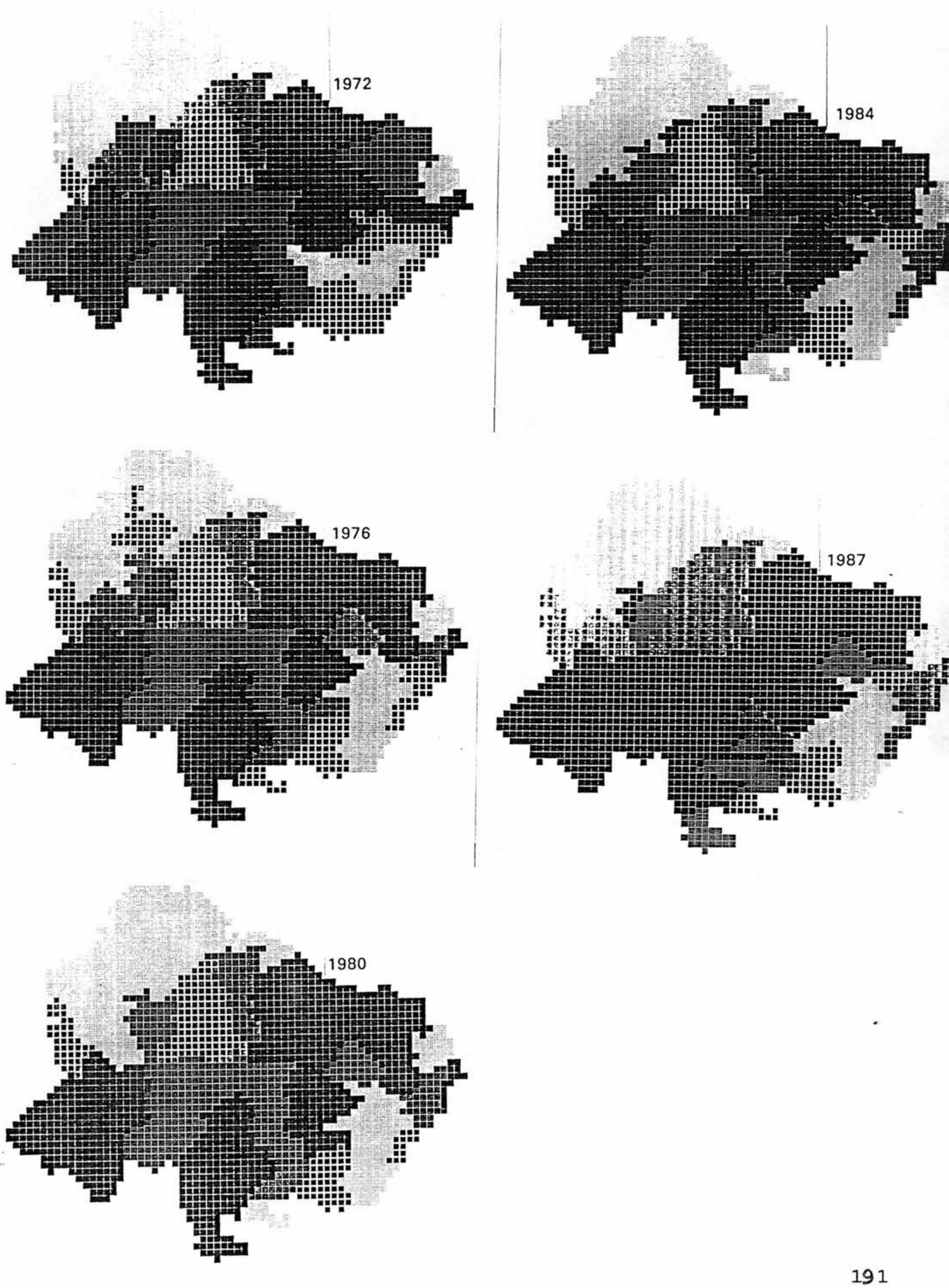


Rough Grazing for Every 100 Hectares of Agricultural Land

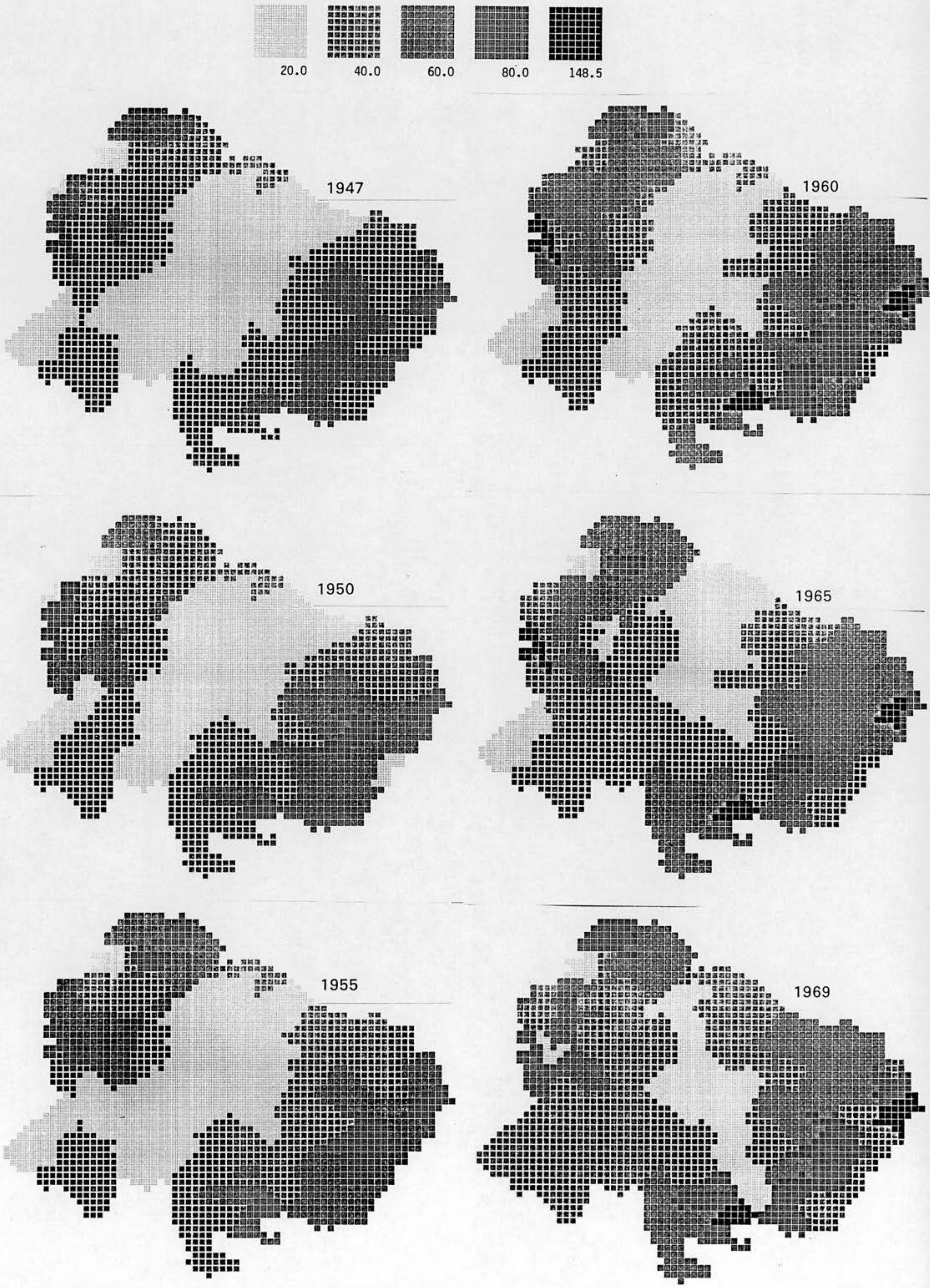
Sheep Number for Every 100 Hectares of Agricultural Land



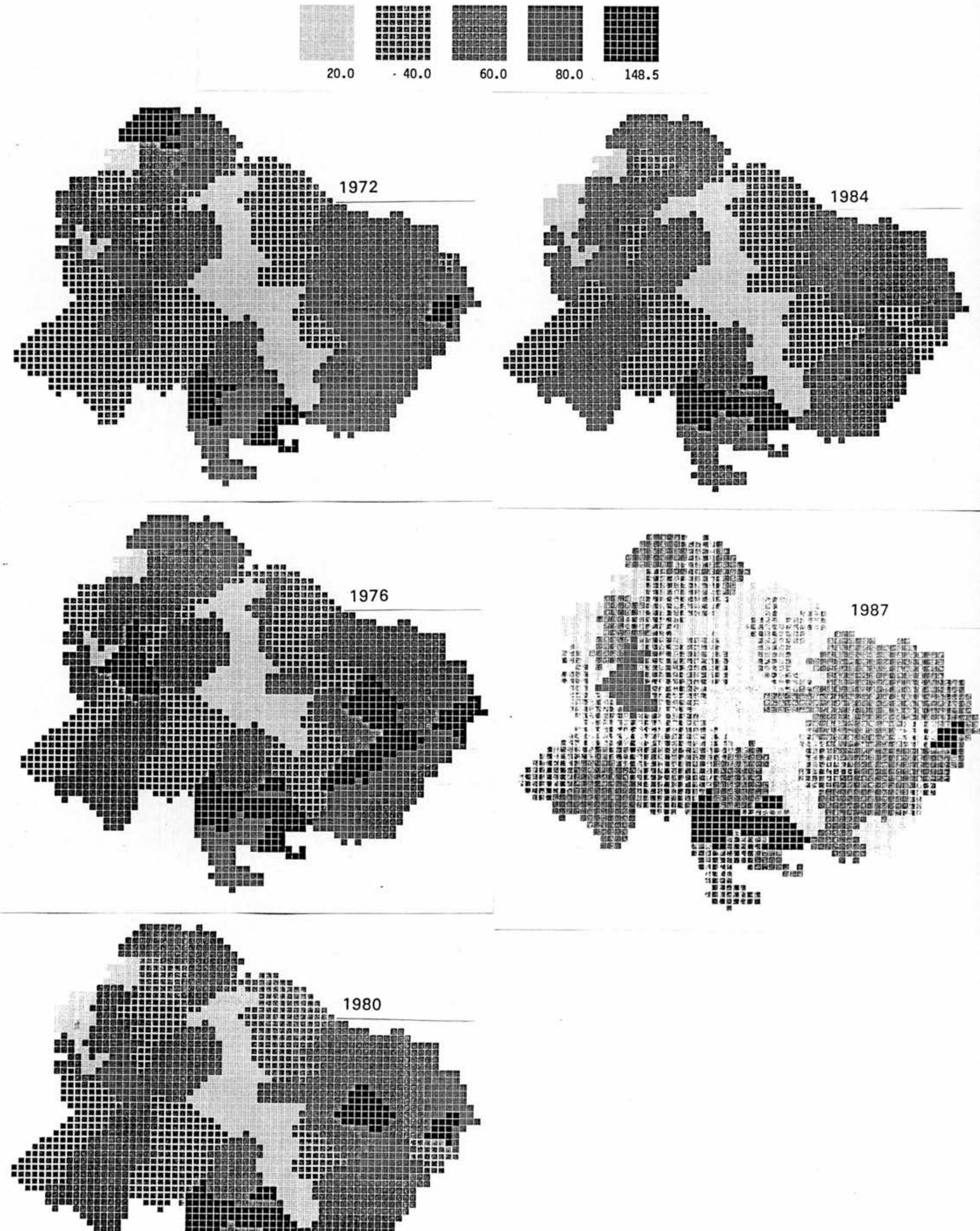
Sheep Number for Every 100 Hectares of Agricultural Land



Cattle Number for Every 100 Hectares of Agricultural Land



Cattle Number for Every 100 Hectares of Agricultural Land



APPENDIX 3

Correlation Coefficients

		Percentage of Total Agricultural Land			
Row	Year	Arable	Grazing	Woodland	Pasture
1	1947	43.99	20.85	*	35.16
2	1950	42.12	22.47	*	36.15
3	1955	38.83	21.84	*	39.33
4	1960	38.24	20.77	1.66	38.62
5	1965	40.90	21.26	1.80	35.18
6	1969	44.39	21.12	1.91	31.67
7	1970	44.72	21.09	1.91	31.34
8	1971	45.25	20.82	1.87	31.11
9	1972	45.65	20.79	1.88	30.74
10	1976	45.65	21.28	2.23	29.57
11	1979	47.76	20.43	2.50	28.00
12	1980	48.53	20.37	2.51	27.18
13	1981	48.71	21.51	2.55	25.97
14	1984	53.06	19.15	2.81	23.57
15	1985	52.94	18.53	2.97	23.18
16	1986	53.62	19.08	2.99	22.94
17	1987	54.42	18.52	3.02	22.79

Correlation Coefficients

	Year	Arable	Grazing	Woodland
Arable	0.850			
Grazing	-0.730	-0.827		
Woodland	0.968	0.952	-0.808	
Pasture	-0.924	-0.980	0.782	-0.951

Note: The values used in top the table are the means for the sixty-one parishes, regarding the proportions of arable land, rough grazing, farm woodland and grassland respectively.

1947	arable	grazing	woodland	cattle	sheep
grazing	-0.899				
woodland	*	*			
cattle	0.604	-0.762	*		
sheep	-0.701	0.376	*	-0.260	
pasture	0.080	-0.509	*	0.547	0.523

1950	arable	grazing	woodland	cattle	sheep
grazing	-0.854				
woodland	*	*			
cattle	0.441	-0.736	*		
sheep	-0.716	0.322	*	-0.012	
pasture	0.127	-0.621	*	0.721	0.454

1955	arable	grazing	woodland	cattle	sheep
grazing	-0.841				
woodland	*	*			
cattle	0.607	-0.811	*		
sheep	-0.687	0.280	*	-0.199	
pasture	0.054	-0.585	*	0.588	0.513

1960	arable	grazing	woodland	cattle	sheep
grazing	-0.833				
woodland	-0.096	-0.081			
cattle	0.496	-0.728	0.121		
sheep	-0.693	0.308	0.281	-0.167	
pasture	-0.008	-0.544	0.203	0.566	0.485

1965	arable	grazing	woodland	cattle	sheep
grazing	-0.876				
woodland	-0.209	-0.044			
cattle	0.348	-0.571	0.166		
sheep	-0.704	0.368	0.407	-0.171	
pasture	-0.053	-0.432	0.379	0.534	0.545

1969	arable	grazing	woodland	cattle	sheep
grazing	-0.875				
woodland	-0.124	-0.033			
cattle	0.252	-0.493	0.081		
sheep	-0.799	0.515	0.322	-0.118	
pasture	-0.184	-0.311	0.197	0.503	0.507

1970	arable	grazing	woodland	cattle	sheep
grazing	-0.865				
woodland	-0.200	-0.027			
cattle	0.259	-0.521	0.140		
sheep	-0.825	0.545	0.316	-0.128	
pasture	-0.225	-0.291	0.335	0.515	0.511

1971	arable	grazing	woodland	cattle	sheep
grazing	-0.841				
woodland	-0.187	0.009			
cattle	0.132	-0.442	0.161		
sheep	-0.815	0.546	0.358	0.058	
pasture	-0.321	-0.239	0.228	0.526	0.492

1972	arable	grazing	woodland	cattle	sheep
grazing	-0.837				
woodland	-0.199	-0.010			
cattle	0.207	-0.436	0.232		
sheep	-0.774	0.576	0.340	0.085	
pasture	-0.364	-0.201	0.275	0.350	0.389

1976	arable	grazing	woodland	cattle	sheep
grazing	-0.894				
woodland	-0.102	-0.094			
cattle	0.114	-0.420	0.111		
sheep	-0.831	0.608	0.213	0.035	
pasture	0.276	-0.179	0.298	0.668	

1979	arable	grazing	woodland	cattle	sheep
grazing	-0.886				
woodland	-0.153	-0.074			
cattle	0.070	-0.378	0.298		
sheep	-0.797	-.594	0.187	0.064	
pasture	-0.392	-0.072	0.342	0.594	0.544

1980	arable	grazing	woodland	cattle	sheep
grazing	-0.889				
woodland	-0.176	-0.045			
cattle	0.029	-0.342	0.340		
sheep	-0.797	0.579	0.158	0.061	
pasture	-0.421	-0.036	0.335	0.595	0.608

1984	arable	grazing	woodland	cattle	sheep
grazing	-0.896				
woodland	-0.043	-0.167			
cattle	0.010	-0.334	0.406		
sheep	-0.797	0.546	0.116	0.147	
pasture	-0.484	0.052	0.283	0.623	0.723

1985	arable	grazing	woodland	cattle	sheep
grazing	-0.900				
woodland	-0.144	-0.069			
cattle	0.080	-0.376	0.328		
sheep	-0.799	0.559	0.218	0.122	
pasture	-0.434	0.008	0.325	0.590	0.682

Note: The correlation coefficients for each year were obtained using the data for the sixty-one parishes within the same year, regarding the proportions of arable land, rough grazing, farm woodland, grassland and densities of cattle and sheep.

APPENDIX 4

Details of the Geometric Correction

GROUND CONTROL POINTS FOR MSS IMAGE ANALYSIS

Landsat 5 205/21 24-04-84. 55.702 19.674

				Map coordinates		Image coordinates		Description
GCP	UK	67	1	366400.	656650.	2818.0	996.0	WATCH WATER RESR
GCP	UK	67	2	345450.	657550.	2464.0	1055.0	KING'S INCH
GCP	UK	67	3	346800.	655840.	2495.0	1070.0	FOREST
GCP	UK	66	4	317500.	664410.	1964.5	1069.5	THREIPMUIR RESR
GCP	UK	66	5	321600.	664090.	2034.0	1059.5	GLENCORSE RESR
GCP	UK	67	6*	364100.	673400.	2698.5	811.0	PRESSMENNAN WOOD
GCP	UK	66	7*	351650.	668550.	2514.5	908.0	INCLISFIELD
GCP	UK	66	8*	332370.	655360.	2256.5	1124.0	COCKMOOR WOOD
GCP	UK	66	9*	355000.	662050.	2602.0	972.0	HOPES RESR
GCP	UK	66	10	354950.	662240.	2600.0	970.5	HOPES RESR
GCP	UK	67	11*	366050.	663250.	2779.5	921.5	whiteadder resr
GCP	UK	67	12	365700.	663620.	2772.5	919.0	WHITEADDER RESR
GCP	UK	67	13*	369200.	668200.	2808.5	854.0	WHITE CLAUGH
GCP	UK	66	14	321000.	687700.	1911.5	789.0	STENHOUSE RESR
GCP	UK	66	15	323830.	685600.	1968.0	804.0	DOCKS
GCP	UK	66	16*	330800.	656700.	2223.5	1114.0	ROSEBERY RESR
GCP	UK	66	17	319350.	687600.	1883.0	796.5	GALLALOE RESR
GCP	UK	57	18	249100.	707870.	616.5	795.5	ELLEN'S ISLE
GCP	UK	57	19	259710.	706490.	801.0	777.0	LOCH VENARCHAR
GCP	UK	51	20	265800.	758260.	654.0	159.6	LOCH RANNOCH
GCP	UK	51	21*	276650.	745400.	896.5	272.3	LOCH TAY
GCP	UK	51	22*	272600.	728800.	908.3	476.5	LOCH LEDNOCK RESR
GCP	UK	51	23	269500.	723900.	879.7	543.1	LOCH EARN
GCP	UK	57	24	270050.	689300.	1055.0	940.0	
GCP	UK	57	25	271670.	683900.	1107.1	997.5	CARRON VAL RESR
GCP	UK	57	26*	281000.	693700.	1216.5	853.0	
GCP	UK	57	27	269800.	715910.	924.0	634.5	
GCP	UK	51	28	279300.	748000.	927.5	232.9	REPL
GCP	UK	57	29*	252050.	709850.	656.5	762.5	LOCH VENARCHAR
GCP	UK	57	30*	248250.	701100.	634.6	876.0	LOCH ARDL
GCP	UK	51	31*	277100.	745600.	903.2	268.5	

Note: * Ground control points which were actually retained in the analysis. See also the residual tables.

GROUND CONTROL POINTS FOR TM IMAGE ANALYSIS

Landsat 5 204/21 14-09-86 55.702 21.108

				Map coordinates		Image coordinates		Description
GCP	UK	67	1	361650.	677450.	2387.0	2946.5	JUNCTION
GCP	UK	67	2*	365300.	677450.	2504.0	2915.0	JUNCTION
GCP	UK	67	3*	369800.	676450.	2657.0	2909.0	JUNCTION
GCP	UK	67	4*	369200.	668200.	2708.5	3181.0	WHITE CLEUGH
GCP	UK	67	5*	363710.	679500.	2435.0	2863.0	HECKIES HOLE
GCP	UK	67	6	360350.	664510.	2455.0	3374.5	JUNCTION
GCP	UK	67	7*	366080.	663250.	2649.5	3366.0	WHITE ADDER RESR
GCP	UK	67	8*	370500.	663550.	2790.5	3320.0	PHILIP BURN
GCP	UK	67	9*	366400.	656650.	2716.5	3577.5	WATCH WATER RESR
GCP	UK	67	10	376430.	657920.	3029.0	3450.5	MILLBURN BRIDGE
GCP	UK	67	11	373430.	674870.	2787.0	2929.5	SKATERAW
GCP	UK	66	12	345500.	676820.	1871.5	3105.5	JUCTION
GCP	UK	66	13	350200.	668330.	2093.0	3339.0	JUNCTION
GCP	UK	66	14*	354960.	662250.	2300.5	3494.5	HOPES RESR
GCP	UK	67	15*	364700.	650350.	2714.5	3796.0	JUNCTION
GCP	UK	67	16*	358160.	651050.	2497.5	3829.5	JUNCTION
GCP	UK	66	17	317950.	685050.	911.5	3075.5	JUNCTION
GCP	UK	66	18	319510.	678150.	1021.5	3282.0	KNOLL,CRAMOND
GCP	UK	66	19	3129000.	677150.	817.5	3370.5	JUNCTION
GCP	UK	66	20	314200.	677120.	858.5	3361.5	JUNCTION
GCP	UK	66	21	312500.	672680.	842.5	3519.0	ROUNDABOUT
GCP	UK	66	22*	323450.	655450.	1341.0	3982.5	JUNCTION INN
GCP	UK	66	23	324750.	658800.	1355.5	3863.0	JUNCTION
GCP	UK	66	24	346260.	654900.	2079.5	3805.0	FOREST
GCP	UK	66	25	377370.	642640.	3189.5	3935.0	JUNCTION
GCP	UK	66	26	370500.	645300.	2946.0	3907.0	JUNCTION
GCP	UK	66	27	316380.	642900.	1219.5	4447.0	JUNCTION

Calculating a Transformation from the Ground Control Points

To carry out the geometric correction of the images for the study area, six coefficients were used to fit the **X,Y** pairs with a second order polynomial to achieve correction accuracy. Weighted least squares are used by the program to select which points are included in the analysis and which are excluded. With a rejection level of 2, those ground control points with a weight of 1 were retained for subsequent use whilst those with a weight of 0 were deleted from the analysis.

1. Transformation for TM Data

Among the 27 Observations, 16 were rejected. EPS is 0.1923 0.3247, Central pixel size 30.0 29.9, RMS Distance Error 11.3(m).

	Residuals		Weighted			
	Column	Row	Column	Row	Weight	SD
1.	0.4773	0.0950	2.5	0.3	0.00	0.91
2.	0.1695	-0.3208	0.9	-1.0	1.00	0.56
3.	-0.0880	-0.3208	-0.5	-0.7	1.00	0.78
4.	-0.1745	0.2867	-0.9	0.9	1.00	0.57
5.	-0.0530	0.3376	-0.3	1.0	1.00	0.81
6.	-0.1389	-1.0666	-0.7	-3.3	0.00	0.74
7.	-0.8777	-1.2852	-4.6	-4.0	0.00	0.54
8.	0.3055	0.2643	1.6	0.8	1.00	0.54
9.	0.0196	-0.2668	0.1	-0.8	1.00	0.44
10.	-0.1089	-0.0927	-0.6	-0.3	1.00	0.87
11.	-0.4185	0.2884	-2.2	0.9	0.00	1.14
12.	-1.2721	1.6311	-6.6	5.0	0.00	3.55
13.	-2.9951	0.4347	-15.6	1.3	0.00	1.61
14.	-0.0847	-0.1297	-0.4	-0.4	1.00	0.87
15.	0.0346	0.0584	0.2	0.2	1.00	0.72
16.	-0.0319	0.0822	-0.2	0.3	1.00	0.78
17.	-6.1497	6.1454	-32.0	18.9	0.00	13.29
18.	-4.3939	2.1137	-22.9	6.5	0.00	9.70
19.	-4.1968	2.7843	-21.8	8.6	0.00	10.98

20.	-5.2581	3.7017	-27.3	11.4	0.00	10.62
21.	-3.5385	2.9765	-18.4	9.2	0.00	8.91
22.	0.0117	0.0078	0.1	0.0	1.00	1.00
23.	0.0686	0.1006	0.4	0.3	0.00	1.48
24.	-2.0165	-1.5842	-10.5	-4.9	0.00	0.89
25.	1.5119	-0.8627	7.9	-2.7	0.00	3.32
26.	2.1336	-2.2331	11.1	-6.9	0.00	1.81
27.	5.1475	-2.4194	26.8	-7.5	0.00	5.49

2. Transformation for MSS Data

Thirty-one observations in total and 18 were rejected. EPS is 0.2812, 0.1362, Central Pixel Size 57.7 x 83.5, RMS Distance Error 19.8(m).

	Residuals		Weighted			
	Column	Row	Column	Row	Weight	SD
1.	0.6552	-0.1684	2.3	-1.2	0.00	0.96
2.	0.0418	-0.4362	0.1	-3.2	0.00	0.61
3.	0.3457	-0.6432	0.1	-4.7	0.00	0.69
4.	-0.6370	0.2280	-2.3	1.7	0.00	0.77
5.	-1.0395	0.1586	-3.7	1.2	0.00	0.69
6.	-0.0417	-0.0777	-0.1	-0.6	1.00	0.70
7.	-0.0025	-0.1996	0.0	-1.5	1.00	0.46
8.	0.1055	-0.1417	0.4	-1.0	1.00	0.68
9.	0.4892	0.1093	1.7	0.8	1.00	0.52
10.	0.2341	0.6303	0.8	4.6	0.00	0.51
11.	-0.3067	0.1247	-1.1	0.9	1.00	0.59
12.	0.3003	0.7198	1.1	5.3	0.00	0.57
13.	0.0369	0.0344	0.1	0.3	1.00	0.59
14.	-0.4869	-0.4472	-1.7	-3.3	0.00	1.18
15.	-1.2103	-0.2398	-4.3	-1.8	0.00	1.13
16.	-0.3035	0.0795	-1.1	0.6	1.00	0.65
17.	-1.9707	0.4348	-7.0	3.2	0.00	1.17
18.	-0.0907	0.3506	-0.3	2.6	0.00	0.73
19.	0.7898	1.0375	2.8	7.6	0.00	0.58
20.	-0.1483	-0.5864	-0.5	-4.3	0.00	1.40
21.	-0.0187	0.0217	-0.1	0.2	1.00	0.68
22.	-0.2596	-0.0283	-0.9	-0.2	1.00	0.74
23.	-0.6291	-0.0424	-2.2	-0.3	0.00	0.83
24.	0.2818	0.1734	1.0	1.3	0.00	0.91
25.	-0.3965	0.7939	-1.4	5.8	0.00	1.18
26.	0.0891	0.1457	0.3	1.1	1.00	0.84
27.	0.4728	0.3790	1.7	2.8	0.00	0.79
28.	-0.6839	-0.7672	-2.4	-5.6	0.00	0.88
29.	0.1192	-0.0800	0.4	-0.6	1.00	0.72
30.	-0.0525	0.0092	-0.2	0.1	1.00	0.85
31.	0.1452	0.0028	0.5	0.0	1.00	0.70

APPENDIX 5

Saved Statistics for the TM and MSS image classifications

Ficlas.sta

Saved statistics file for TM image classification on the non-urban areas.

```
/*          GEMSTONE  save file
/*
TYPE            CL.STAT
PARAMS      CLASSES      25      IMAGES       3
LOWER9       4       2
UPPER 210     200     254
CLASS  NUMBER         1      NAME          deep_water
MEANS9.72234 5.50266 3.43351
COVARS  LINE    1 VALUES          5.87793E-1        2.40095E-1        1.31538E-1
COVARS  LINE    2 VALUES          2.40095E-1        9.54245E-1        3.09750E-1
COVARS  LINE    3 VALUES          1.31538E-1        3.09750E-1        8.77494E-1
CLASS  NUMBER         2      NAME     SHALLOW_WATER
MEANS     17.3952  7.10345            4.02122
COVARS  LINE    1 VALUES            24.6846           7.11561          -1.34791
COVARS  LINE    2 VALUES            7.11561           6.17762           1.31080
COVARS  LINE    3 VALUES           -1.34791           1.31080           3.10300
CLASS  NUMBER         3      NAME     CLOUD_SHADOW
MEANS     11.1014  14.7699            8.87534
COVARS  LINE    1 VALUES            1.84452          -1.16845        5.52366E-1
COVARS  LINE    2 VALUES           -1.16845           8.48951           3.07406
COVARS  LINE    3 VALUES          5.52366E-1          3.07406           3.88446
CLASS  NUMBER         4      NAME          golfgrass
MEANS     20.9343  86.7183            76.0470
COVARS  LINE    1 VALUES            3.84543          -3.51613           6.36921
COVARS  LINE    2 VALUES           -3.51613           53.7615           15.2996
COVARS  LINE    3 VALUES            6.36921           15.2996           38.7956
CLASS  NUMBER         5      NAME       bright_pasture
MEANS     19.8140  115.279            77.1977
COVARS  LINE    1 VALUES            10.7561          -7.25037           17.4204
COVARS  LINE    2 VALUES           -7.25037           112.388           18.5143
COVARS  LINE    3 VALUES            17.4204           18.5143           49.8558
CLASS  NUMBER         6      NAME          pasture2
MEANS     17.8623  99.0120            60.2036
COVARS  LINE    1 VALUES            2.92114           1.56449           5.79448
COVARS  LINE    2 VALUES            1.56449           130.742           48.6861
COVARS  LINE    3 VALUES            5.79448           48.6861           40.9765
CLASS  NUMBER         7      NAME  CEREAL
```

MEANS 29.9969 59.8287 44.2722
COVARS LINE 1 VALUES 31.2569 11.1891 25.9856
COVARS LINE 2 VALUES 11.1891 50.1481 -4.70561
COVARS LINE 3 VALUES 25.9856 -4.70561 58.1982
CLASS NUMBER 8 NAME cereal2
MEANS 36.7119 79.7627 62.3898
COVARS LINE 1 VALUES 22.2051 -1.86967E-1 19.8072
COVARS LINE 2 VALUES -1.86967E-1 28.8253 11.6518
COVARS LINE 3 VALUES 19.8072 11.6518 27.8310
CLASS NUMBER 9 NAME roots
MEANS 16.9174 94.2455 37.6362
COVARS LINE 1 VALUES 2.19188 2.66773 4.71999
COVARS LINE 2 VALUES 2.66773 104.337 46.1965
COVARS LINE 3 VALUES 4.71999 46.1965 83.2895
CLASS NUMBER 10 NAME fallow1
MEANS 53.5768 63.5631 106.314
COVARS LINE 1 VALUES 41.4110 46.6067 27.4873
COVARS LINE 2 VALUES 46.6067 62.3891 29.6999
COVARS LINE 3 VALUES 27.4873 29.6999 44.1532
CLASS NUMBER 11 NAME fallow2
MEANS 38.8202 41.4270 74.8258
COVARS LINE 1 VALUES 6.21488 4.85762 12.5473
COVARS LINE 2 VALUES 4.85762 12.9974 14.2990
COVARS LINE 3 VALUES 12.5473 14.2990 47.5033
CLASS NUMBER 12 NAME fallow3
MEANS 27.0095 24.7810 42.9381
COVARS LINE 1 VALUES 6.96186 6.32593 11.9007
COVARS LINE 2 VALUES 6.32593 7.28537 14.5722
COVARS LINE 3 VALUES 11.9007 14.5722 39.1439
CLASS NUMBER 13 NAME fallow4
MEANS 36.7069 67.1897 86.1379
COVARS LINE 1 VALUES 11.3450 7.69357 12.6782
COVARS LINE 2 VALUES 7.69357 41.5680 9.45684
COVARS LINE 3 VALUES 12.6782 9.45684 17.3601
CLASS NUMBER 14 NAME fallow5
MEANS 48.4881 65.5833 76.0833
COVARS LINE 1 VALUES 10.7500 7.42956 13.3998
COVARS LINE 2 VALUES 7.42956 28.7904 7.78445
COVARS LINE 3 VALUES 13.3998 7.78445 26.9571
CLASS NUMBER 15 NAME FALLOW6
MEANS 25.3226 29.1290 55.0323

COVARS LINE 1 VALUES		3.83142	5.66804	4.95734
COVARS LINE 2 VALUES		5.66804	10.1769	8.18937
COVARS LINE 3 VALUES		4.95734	8.18937	9.77317
CLASS NUMBER 16	NAME	FALLOW7		
MEANS 45.4762 43.4490		69.6939		
COVARS LINE 1 VALUES		176.685	160.358	284.302
COVARS LINE 2 VALUES		160.358	171.703	286.512
COVARS LINE 3 VALUES		284.302	286.512	575.505
CLASS NUMBER 17	NAME	moors		
MEANS 16.6698 58.7480		43.2878		
COVARS LINE 1 VALUES		3.11506	3.89556	5.70242
COVARS LINE 2 VALUES		3.89556	23.4274	11.5194
COVARS LINE 3 VALUES		5.70242	11.5194	19.7963
CLASS NUMBER 18	NAME	dark_moors		
MEANS 14.6179 47.0000		36.2488		
COVARS LINE 1 VALUES		2.53661	5.32640	4.82642
COVARS LINE 2 VALUES		5.32640	33.7414	21.5881
COVARS LINE 3 VALUES		4.82642	21.5881	21.0526
CLASS NUMBER 19	NAME	grey_moors		
MEANS 16.5572 40.0547		39.9154		
COVARS LINE 1 VALUES		2.52530	1.67345	5.14158
COVARS LINE 2 VALUES		1.67345	11.0219	6.45481
COVARS LINE 3 VALUES		5.14158	6.45481	18.6693
CLASS NUMBER 20	NAME	steep&shadow		
MEANS 15.1132 37.0882		29.2985		
COVARS LINE 1 VALUES		3.62394	14.0900	12.8103
COVARS LINE 2 VALUES		14.0900	97.7070	78.2914
COVARS LINE 3 VALUES		12.8103	78.2914	72.3742
CLASS NUMBER 21	NAME	burnt		
MEANS 21.2684 41.8971		68.7794		
COVARS LINE 1 VALUES		5.44633	3.58639	12.8092
COVARS LINE 2 VALUES		3.58639	53.9966	11.8191
COVARS LINE 3 VALUES		12.8092	11.8191	63.5544
CLASS NUMBER 22	NAME	moor2		
MEANS 26.8817 65.4839		66.5376		
COVARS LINE 1 VALUES		1.91079	1.72394	8.48554E-1
COVARS LINE 2 VALUES		1.72394	14.8948	8.27736
COVARS LINE 3 VALUES		8.48554E-1	8.27736	9.79678
CLASS NUMBER 23	NAME	moor3		
MEANS 25.3006 83.0368		66.6196		
COVARS LINE 1 VALUES		4.65195	3.36308	8.45794

```
COVARS LINE   2 VALUES        3.36308     31.7405     30.5968
COVARS LINE   3 VALUES        8.45794     30.5968     44.8249
CLASS NUMBER      24     NAME       clouds
MEANS     131.575  142.775    194.069
COVARS LINE   1 VALUES        1531.95     940.506     1359.75
COVARS LINE   2 VALUES        940.506     655.451     877.362
COVARS LINE   3 VALUES        1359.75     877.362     1401.93
CLASS NUMBER      25     NAME       forest
MEANS     12.5977  46.6578    21.8342
COVARS LINE   1 VALUES        8.57948E-1  4.11405     2.05650
COVARS LINE   2 VALUES        4.11405     92.2980     24.4953
COVARS LINE   3 VALUES        2.05650     24.4953     19.7565
END
```

Thclas.sta

Saved statistics file for TM image classification on the areas without rough moors, with those statistics defined for the moorland spectral classes being removed.

```
/*          GEMSTONE  save file
/*
TYPE  CL.STAT
PARAMS  CLASSES     28      IMAGES       3
LOWER9        4       2
UPPER 210     200     254
CLASS  NUMBER         1     NAME          deep_water
MEANS     9.72234  5.50266           3.43351
COVARS  LINE    1 VALUES           5.87793E-1     2.40095E-1     1.31538E-1
COVARS  LINE    2 VALUES           2.40095E-1     9.54245E-1     3.09750E-1
COVARS  LINE    3 VALUES           1.31538E-1     3.09750E-1     8.77494E-1
CLASS  NUMBER         2     NAME     SHALLOW_WATER
MEANS     17.3952  7.10345           4.02122
COVARS  LINE    1 VALUES           24.6846        7.11561        -1.34791
COVARS  LINE    2 VALUES           7.11561        6.17762        1.31080
COVARS  LINE    3 VALUES           -1.34791       1.31080        3.10300
CLASS  NUMBER         3     NAME     CLOUD_SHADOW
MEANS     11.1014  14.7699           8.87534
COVARS  LINE    1 VALUES           1.84452        -1.16845       5.52366E-1
COVARS  LINE    2 VALUES           -1.16845       8.48951        3.07406
COVARS  LINE    3 VALUES           5.52366E-1     3.07406        3.88446
CLASS  NUMBER         4     NAME          golfgrass
MEANS     20.9343  86.7183           76.0470
COVARS  LINE    1 VALUES           3.84543        -3.51613       6.36921
COVARS  LINE    2 VALUES           -3.51613       53.7615        15.2996
COVARS  LINE    3 VALUES           6.36921        15.2996        38.7956
CLASS  NUMBER         5     NAME          bright_pasture
MEANS     19.8140  115.279           77.1977
COVARS  LINE    1 VALUES           10.7561        -7.25037       17.4204
COVARS  LINE    2 VALUES           -7.25037       112.388        18.5143
COVARS  LINE    3 VALUES           17.4204        18.5143        49.8558
CLASS  NUMBER         6     NAME          pasture2
MEANS     17.8623  99.0120           60.2036
COVARS  LINE    1 VALUES           2.92114        1.56449        5.79448
COVARS  LINE    2 VALUES           1.56449        130.742        48.6861
COVARS  LINE    3 VALUES           5.79448        48.6861        40.9765
```

CLASS NUMBER	7	NAME	CEREAL		
MEANS	29.9969 59.8287		44.2722		
COVARS LINE	1 VALUES		31.2569	11.1891	25.9856
COVARS LINE	2 VALUES		11.1891	50.1481	-4.70561
COVARS LINE	3 VALUES		25.9856	-4.70561	58.1982
CLASS NUMBER	8	NAME	cereal2		
MEANS	36.7119 79.7627		62.3898		
COVARS LINE	1 VALUES		22.2051	-1.86967E-1	19.8072
COVARS LINE	2 VALUES		-1.86967E-1	28.8253	11.6518
COVARS LINE	3 VALUES		19.8072	11.6518	27.8310
CLASS NUMBER	9	NAME	roots		
MEANS	16.9174 94.2455		37.6362		
COVARS LINE	1 VALUES		2.19188	2.66773	4.71999
COVARS LINE	2 VALUES		2.66773	104.337	46.1965
COVARS LINE	3 VALUES		4.71999	46.1965	83.2895
CLASS NUMBER	10	NAME	fallow1		
MEANS	53.5768 63.5631		106.314		
COVARS LINE	1 VALUES		41.4110	46.6067	27.4873
COVARS LINE	2 VALUES		46.6067	62.3891	29.6999
COVARS LINE	3 VALUES		27.4873	29.6999	44.1532
CLASS NUMBER	11	NAME	fallow2		
MEANS	38.8202 41.4270		74.8258		
COVARS LINE	1 VALUES		6.21488	4.85762	12.5473
COVARS LINE	2 VALUES		4.85762	12.9974	14.2990
COVARS LINE	3 VALUES		12.5473	14.2990	47.5033
CLASS NUMBER	12	NAME	fallow3		
MEANS	27.0095 24.7810		42.9381		
COVARS LINE	1 VALUES		6.96186	6.32593	11.9007
COVARS LINE	2 VALUES		6.32593	7.28537	14.5722
COVARS LINE	3 VALUES		11.9007	14.5722	39.1439
CLASS NUMBER	13	NAME	fallow4		
MEANS	36.7069 67.1897		86.1379		
COVARS LINE	1 VALUES		11.3450	7.69357	12.6782
COVARS LINE	2 VALUES		7.69357	41.5680	9.45684
COVARS LINE	3 VALUES		12.6782	9.45684	17.3601
CLASS NUMBER	14	NAME	fallow5		
MEANS	48.4881 65.5833		76.0833		
COVARS LINE	1 VALUES		10.7500	7.42956	13.3998
COVARS LINE	2 VALUES		7.42956	28.7904	7.78445
COVARS LINE	3 VALUES		13.3998	7.78445	26.9571
CLASS NUMBER	15	NAME	FALLOW6		

MEANS 25.3226 29.1290	55.0323		
COVARS LINE 1 VALUES	3.83142	5.66804	4.95734
COVARS LINE 2 VALUES	5.66804	10.1769	8.18937
COVARS LINE 3 VALUES	4.95734	8.18937	9.77317
CLASS NUMBER 16 NAME	FALLOW7		
MEANS 45.4762 43.4490	69.6939		
COVARS LINE 1 VALUES	176.685	160.358	284.302
COVARS LINE 2 VALUES	160.358	171.793	286.512
COVARS LINE 3 VALUES	284.302	286.512	575.505
CLASS NUMBER 24 NAME	clouds		
MEANS 131.575 142.775	194.069		
COVARS LINE 1 VALUES	1531.95	940.506	1359.75
COVARS LINE 2 VALUES	940.506	655.451	877.362
COVARS LINE 3 VALUES	1359.75	877.362	1401.93
CLASS NUMBER 25 NAME	forest		
MEANS 12.5977 46.6578	21.8342		
COVARS LINE 1 VALUES	8.57948E-1	4.11405	2.05650
COVARS LINE 2 VALUES	4.11405	92.2980	24.4953
COVARS LINE 3 VALUES	2.05650	24.4953	19.7565
CLASS NUMBER 26 NAME	WOODLANDS		
MEANS 13.6352 52.6276	36.1199		
COVARS LINE 1 VALUES	2.36946	5.58603	4.74778
COVARS LINE 2 VALUES	5.58603	96.9325	41.3557
COVARS LINE 3 VALUES	4.74778	41.3557	39.4370
CLASS NUMBER 27 NAME	built_up1		
MEANS 25.6875 22.3958	33.7083		
COVARS LINE 1 VALUES	31.1940	29.1758	41.1589
COVARS LINE 2 VALUES	29.1758	35.0516	45.8863
COVARS LINE 3 VALUES	41.1589	45.8863	93.4151
CLASS NUMBER 28 NAME	built_up2		
MEANS 21.0208 36.8906	37.0885		
COVARS LINE 1 VALUES	13.5621	-5.57585	13.7117
COVARS LINE 2 VALUES	-5.57585	33.0454	11.3638
COVARS LINE 3 VALUES	13.7117	11.3638	31.9036

END

Seclas.sta

Saved statistics file showing full information on the statistics used for the TM image classification of the study area.

```
/*          GEMSTONE save file
/*
TYPE CL.STAT
PARAMS CLASSES    28     IMAGES     3
LOWER9     4     2
UPPER 210     200     254
CLASS NUMBER     1     NAME     deep_water
MEANS     9.72234  5.50266     3.43351
COVARS LINE  1 VALUES     5.87793E-1     2.40095E-1     1.31538E-1
COVARS LINE  2 VALUES     2.40095E-1     9.54245E-1     3.09750E-1
COVARS LINE  3 VALUES     1.31538E-1     3.09750E-1     8.77494E-1
CLASS NUMBER     2     NAME     SHALLOW_WATER
MEANS     17.3952  7.10345     4.02122
COVARS LINE  1 VALUES     24.6846     7.11561     -1.34791
COVARS LINE  2 VALUES     7.11561     6.17762     1.31080
COVARS LINE  3 VALUES     -1.34791     1.31080     3.10300
CLASS NUMBER     3     NAME     CLOUD_SHADOW
MEANS     11.1014  14.7699     8.87534
COVARS LINE  1 VALUES     1.84452     -1.16845     5.52366E-1
COVARS LINE  2 VALUES     -1.16845     8.48951     3.07406
COVARS LINE  3 VALUES     5.52366E-1     3.07406     3.88446
CLASS NUMBER     4     NAME     golfgrass
MEANS     20.9343  86.7183     76.0470
COVARS LINE  1 VALUES     3.84543     -3.51613     6.36921
COVARS LINE  2 VALUES     -3.51613     53.7615     15.2996
COVARS LINE  3 VALUES     6.36921     15.2996     38.7956
CLASS NUMBER     5     NAME     bright_pasture
MEANS     19.8140  115.279     77.1977
COVARS LINE  1 VALUES     10.7561     -7.25037     17.4204
COVARS LINE  2 VALUES     -7.25037     112.388     18.5143
COVARS LINE  3 VALUES     17.4204     18.5143     49.8558
CLASS NUMBER     6     NAME     pasture2
MEANS     17.8623  99.0120     60.2036
COVARS LINE  1 VALUES     2.92114     1.56449     5.79448
COVARS LINE  2 VALUES     1.56449     130.742     48.6861
```

COVARS LINE 3 VALUES 5.79448 48.6861 40.9765
CLASS NUMBER 7 NAME CEREAL
MEANS 29.9969 59.8287 44.2722
COVARS LINE 1 VALUES 31.2569 11.1891 25.9856
COVARS LINE 2 VALUES 11.1891 50.1481 -4.70561
COVARS LINE 3 VALUES 25.9856 -4.70561 58.1982
CLASS NUMBER 8 NAME cereal2
MEANS 36.7119 79.7627 62.3898
COVARS LINE 1 VALUES 22.2051 -1.86967E-1 19.8072
COVARS LINE 2 VALUES -1.86967E-1 28.8253 11.6518
COVARS LINE 3 VALUES 19.8072 11.6518 27.8310
CLASS NUMBER 9 NAME roots
MEANS 16.9174 94.2455 37.6362
COVARS LINE 1 VALUES 2.19188 2.66773 4.71999
COVARS LINE 2 VALUES 2.66773 104.337 46.1965
COVARS LINE 3 VALUES 4.71999 46.1965 83.2895
CLASS NUMBER 10 NAME fallow1
MEANS 53.5768 63.5631 106.314
COVARS LINE 1 VALUES 41.4110 46.6067 27.4873
COVARS LINE 2 VALUES 46.6067 62.3891 29.6999
COVARS LINE 3 VALUES 27.4873 29.6999 44.1532
CLASS NUMBER 11 NAME fallow2
MEANS 38.8202 41.4270 74.8258
COVARS LINE 1 VALUES 6.21488 4.85762 12.5473
COVARS LINE 2 VALUES 4.85762 12.9974 14.2990
COVARS LINE 3 VALUES 12.5473 14.2990 47.5033
CLASS NUMBER 12 NAME fallow3
MEANS 27.0095 24.7810 42.9381
COVARS LINE 1 VALUES 6.96186 6.32593 11.9007
COVARS LINE 2 VALUES 6.32593 7.28537 14.5722
COVARS LINE 3 VALUES 11.9007 14.5722 39.1439
CLASS NUMBER 13 NAME fallow4
MEANS 36.7069 67.1897 86.1379
COVARS LINE 1 VALUES 11.3450 7.69357 12.6782
COVARS LINE 2 VALUES 7.69357 41.5680 9.45684
COVARS LINE 3 VALUES 12.6782 9.45684 17.3601
CLASS NUMBER 14 NAME fallow5
MEANS 48.4881 65.5833 76.0833
COVARS LINE 1 VALUES 10.7500 7.42956 13.3998
COVARS LINE 2 VALUES 7.42956 28.7904 7.78445
COVARS LINE 3 VALUES 13.3998 7.78445 26.9571

CLASS NUMBER 15	NAME	FALLOW6	
MEANS 25.3226 29.1290	55.0323		
COVARS LINE 1 VALUES	3.83142	5.66804	4.95734
COVARS LINE 2 VALUES	5.66804	10.1769	8.18937
COVARS LINE 3 VALUES	4.95734	8.18937	9.77317
CLASS NUMBER 16	NAME	FALLOW7	
MEANS 45.4762 43.4490	69.6939		
COVARS LINE 1 VALUES	176.685	160.358	284.302
COVARS LINE 2 VALUES	160.358	171.703	286.512
COVARS LINE 3 VALUES	284.302	286.512	575.505
CLASS NUMBER 17	NAME moors		
MEANS 16.6698 58.74804	3.2878		
COVARS LINE 1 VALUES	3.11506	3.89556	5.70242
COVARS LINE 2 VALUES	3.89556	23.4274	11.5194
COVARS LINE 3 VALUES	5.70242	11.5194	19.7963
CLASS NUMBER 18	NAME	dark_moors	
MEANS 14.6179 47.0000	36.2488		
COVARS LINE 1 VALUES	2.53661	5.32640	4.82642
COVARS LINE 2 VALUES	5.32640	33.7414	21.5881
COVARS LINE 3 VALUES	4.82642	21.5881	21.0526
CLASS NUMBER 19	NAME	grey_moors	
MEANS 16.5572 40.0547	39.9154		
COVARS LINE 1 VALUES	2.52530	1.67345	5.14158
COVARS LINE 2 VALUES	1.67345	11.0219	6.45481
COVARS LINE 3 VALUES	5.14158	6.45481	18.6693
CLASS NUMBER 20	NAME	steep&shadow	
MEANS 15.1132 37.0882	29.2985		
COVARS LINE 1 VALUES	3.62394	14.0900	12.8103
COVARS LINE 2 VALUES	14.0900	97.7070	78.2914
COVARS LINE 3 VALUES	12.8103	78.2914	72.3742
CLASS NUMBER 21	NAME	burnt	
MEANS 21.2684 41.8971	68.7794		
COVARS LINE 1 VALUES	5.44633	3.58639	12.8092
COVARS LINE 2 VALUES	3.58639	53.9966	11.8191
COVARS LINE 3 VALUES	12.8092	11.8191	63.5544
CLASS NUMBER 22	NAME	moor2	
MEANS 26.8817 65.4839	66.5376		
COVARS LINE 1 VALUES	1.91079	1.72394	8.48554E-1
COVARS LINE 2 VALUES	1.72394	14.8948	8.27736
COVARS LINE 3 VALUES	8.48554E-1	8.27736	9.79678
CLASS NUMBER 23	NAME	moor3	

```
MEANS      25.3006  83.0368          66.6196
COVARS LINE   1 VALUES               4.65195       3.36308       8.45794
COVARS LINE   2 VALUES               3.36308       31.7405       30.5968
COVARS LINE   3 VALUES               8.45794       30.5968       44.8249
CLASS NUMBER      24     NAME              clouds
MEANS      131.575  142.775          194.069
COVARS LINE   1 VALUES               1531.95       940.506       1359.75
COVARS LINE   2 VALUES               940.506       655.451       877.362
COVARS LINE   3 VALUES               1359.75       877.362       1401.93
CLASS NUMBER      25     NAME              forest
MEANS      12.5977  46.6578          21.8342
COVARS LINE   1 VALUES             8.57948E-1      4.11405       2.05650
COVARS LINE   2 VALUES               4.11405       92.2980       24.4953
COVARS LINE   3 VALUES               2.05650       24.4953       19.7565
CLASS NUMBER      26     NAME         WOODLANDS
MEANS      13.6352  52.6276          36.1199
COVARS LINE   1 VALUES               2.36946       5.58603       4.74778
COVARS LINE   2 VALUES               5.58603       96.9325       41.3557
COVARS LINE   3 VALUES               4.74778       41.3557       39.4370
CLASS NUMBER      27     NAME            built_up1
MEANS      25.6875  22.3958          33.7083
COVARS LINE   1 VALUES               31.1940       29.1758       41.1589
COVARS LINE   2 VALUES               29.1758       35.0516       45.8863
COVARS LINE   3 VALUES               41.1589       45.8863       93.4151
CLASS NUMBER      28     NAME  built_up2
MEANS      21.0208  36.8906          37.0885
COVARS LINE   1 VALUES               13.5621      -5.57585       13.7117
COVARS LINE   2 VALUES              -5.57585       33.0454       11.3638
COVARS LINE   3 VALUES               13.7117       11.3638       31.9036
END
```

Firmss.sta

Saved statistics file for MSS image classification on the non-urban areas.

```
/*          GEMSTONE  save file
/*
TYPE  CL.STAT
PARAMS  CLASSES     19      IMAGES        3
LOWER33       21      9
UPPER 77      85      121
CLASS  NUMBER        2      NAME            RESR
MEANS    36.7415  25.8305             16.2839
COVARS  LINE   1 VALUES               6.25959        2.55367        1.60946
COVARS  LINE   2 VALUES               2.55367        2.58141        1.26847
COVARS  LINE   3 VALUES               1.60946        1.26847        5.33892
CLASS  NUMBER        3      NAME     SHALLOW_WATER
MEANS    48.2186  37.4014             17.2115
COVARS  LINE   1 VALUES               21.7693        31.6721        18.3623
COVARS  LINE   2 VALUES               31.6721        54.8354        37.9617
COVARS  LINE   3 VALUES               18.3623        37.9617        64.5252
CLASS  NUMBER        4      NAME        GOLFGRASS
MEANS    49.0984  37.6197             110.410
COVARS  LINE   1 VALUES               8.16846        10.5639        -10.4448
COVARS  LINE   2 VALUES               10.5639        21.4589        -20.0494
COVARS  LINE   3 VALUES               -10.4448       -20.0494       54.4750
CLASS  NUMBER        5      NAME  PASTURE
MEANS    46.3963  34.8720             112.604
COVARS  LINE   1 VALUES               5.81218        6.06888        -5.72145
COVARS  LINE   2 VALUES               6.06888        10.9408        -11.8742
COVARS  LINE   3 VALUES               -5.72145       -11.8742       128.811
CLASS  NUMBER        6      NAME          CEREAL
MEANS    54.2759  45.4483             83.5862
COVARS  LINE   1 VALUES               5.78579        5.68657        9.61413
COVARS  LINE   2 VALUES               5.68657        12.1438        7.20015E-1
COVARS  LINE   3 VALUES               9.61413        7.20015E-1     80.8291
CLASS  NUMBER        7      NAME  SBARLEY
MEANS    57.5758  58.8485             58.8182
COVARS  LINE   1 VALUES               7.75968        6.46626        4.18073
COVARS  LINE   2 VALUES               6.46626        12.4318        6.09068E-1
COVARS  LINE   3 VALUES               4.18073        6.09068E-1     14.9369
```

CLASS NUMBER 8	NAME	ROOTS	
MEANS 53.3913 52.3913	50.1739		
COVARS LINE 1 VALUES	6.06436	6.10784	5.36685
COVARS LINE 2 VALUES	6.10784	10.3252	3.62772
COVARS LINE 3 VALUES	5.36685	3.62772	12.1438
CLASS NUMBER 9	NAME FALLOW1		
MEANS 69.6347 76.5489	75.9042		
COVARS LINE 1 VALUES	20.2562	22.2764	17.1410
COVARS LINE 2 VALUES	22.2764	37.4409	28.5156
COVARS LINE 3 VALUES	17.1410	28.5156	32.8853
CLASS NUMBER 10	NAME DARKMOOR		
MEANS 34.5643 27.3000	47.5107		
COVARS LINE 1 VALUES	2.73162	1.28433	3.08228E-1
COVARS LINE 2 VALUES	1.28433	2.31719	9.68225E-1
COVARS LINE 3 VALUES	3.08228E-1	9.68225E-1	6.34264
CLASS NUMBER 11	NAME	LIGHTMOOR	
MEANS 43.1840 38.8143	65.8126		
COVARS LINE 1 VALUES	11.3937	12.7838	25.0599
COVARS LINE 2 VALUES	12.7838	19.2416	35.1373
COVARS LINE 3 VALUES	25.0599	35.1373	85.5116
CLASS NUMBER 12	NAME	SNOWMOOR	
MEANS 63.6591 51.8864	55.9621		
COVARS LINE 1 VALUES	25.7398	21.0067	2.18418
COVARS LINE 2 VALUES	21.0067	20.2068	3.67764
COVARS LINE 3 VALUES	2.18418	3.67764	21.6124
CLASS NUMBER 13	NAME	MOOREDGE	
MEANS 61.7702 63.3150	90.5413		
COVARS LINE 1 VALUES	9.83625	10.8373	5.55659
COVARS LINE 2 VALUES	10.8373	19.0909	3.44732
COVARS LINE 3 VALUES	5.55659	3.44732	27.3080
CLASS NUMBER 14	NAME	WETLAND	
MEANS 37.8961 28.9610	29.2727		
COVARS LINE 1 VALUES	4.74253	3.74924	9.89376E-1
COVARS LINE 2 VALUES	3.74924	9.02448	12.2704
COVARS LINE 3 VALUES	9.89376E-1	12.2704	36.8217
CLASS NUMBER 15	NAME	WETMOOR	
MEANS 45.8564 37.8785	48.2541		
COVARS LINE 1 VALUES	2.99601	1.86661	2.08635
COVARS LINE 2 VALUES	1.86661	4.17318	5.59457
COVARS LINE 3 VALUES	2.08635	5.59457	19.3389
CLASS NUMBER 16	NAME	WOODS	

MEANS	40.2256	29.3293	74.9268		
COVARS LINE	1 VALUES		6.06497	6.52329	5.35804
COVARS LINE	2 VALUES		6.52329	12.1477	8.34122
COVARS LINE	3 VALUES		5.25804	8.34122	20.1778
CLASS NUMBER	17	NAME	FOREST		
MEANS	40.0754	29.7626	57.3606		
COVARS LINE	1 VALUES		6.11949	5.42821	4.94702
COVARS LINE	2 VALUES		5.42821	10.6060	7.11496
COVARS LINE	3 VALUES		4.94702	7.11496	29.9691
END					

Thdmss.sta

Saved statistics file for the MSS image classification on the Rural-Urban areas without moorlands.

```
/*          GEMSTONE  save file
/*
TYPE  CL.STAT
PARAMS  CLASSES      19      IMAGES       3
LOWER33        21       9
UPPER 77       85      121
CLASS  NUMBER         1      NAME              SEA
MEANS     38.2623  24.1452              11.2237
COVARS  LINE    1 VALUES                8.25821          3.55073        4.32042E-1
COVARS  LINE    2 VALUES                3.55073          2.92186        3.08797E-1
COVARS  LINE    3 VALUES             4.32042E-1       3.08797E-1        7.33388E-1
CLASS  NUMBER         2      NAME  RESR
MEANS     36.7415  25.8305              16.2839
COVARS  LINE    1 VALUES                6.25959          2.55367           1.60946
COVARS  LINE    2 VALUES                2.55367          2.58141           1.26847
COVARS  LINE    3 VALUES                1.60946          1.26847           5.33892
CLASS  NUMBER         3      NAME      SHALLOW_WATER
MEANS     48.2186  37.4014              17.2115
COVARS  LINE    1 VALUES                21.7693          31.6721           18.3623
COVARS  LINE    2 VALUES                31.6721          54.8354           37.9617
COVARS  LINE    3 VALUES                18.3623          37.9617           64.5252
CLASS  NUMBER         4      NAME         GOLFGRASS
MEANS     49.0984  37.6197              110.410
COVARS  LINE    1 VALUES                8.16846          10.5639          -10.4448
COVARS  LINE    2 VALUES                10.5639          21.4589          -20.0494
COVARS  LINE    3 VALUES               -10.4448         -20.0494           54.4750
CLASS  NUMBER         5      NAME          PASTURE
MEANS     46.3963  34.8720              112.604
COVARS  LINE    1 VALUES                5.81218          6.06888          -5.72145
COVARS  LINE    2 VALUES                6.06888          10.9408          -11.8742
COVARS  LINE    3 VALUES               -5.72145         -11.8742           128.811
CLASS  NUMBER         6      NAME          CEREAL
MEANS     54.2759  45.4483              83.5862
COVARS  LINE    1 VALUES                5.78579          5.68657           9.61413
COVARS  LINE    2 VALUES                5.68657          12.1438        7.20015E-1
COVARS  LINE    3 VALUES                9.61413       7.20015E-1           80.8291
```

CLASS NUMBER	7	NAME	SBARLEY			
MEANS	57.5758	58.8485	58.8182			
COVARS LINE	1 VALUES		7.75968	6.46626	4.18073	
COVARS LINE	2 VALUES		6.46626	12.4318	6.09068E-1	
COVARS LINE	3 VALUES		4.18073	6.09068E-1	14.9369	
CLASS NUMBER	8	NAME	ROOTS			
MEANS	53.3913	52.3913	50.1739			
COVARS LINE	1 VALUES		6.06436	6.10784	5.36685	
COVARS LINE	2 VALUES		6.10784	10.3252	3.62772	
COVARS LINE	3 VALUES		5.36685	3.62772	12.1438	
CLASS NUMBER	9	NAME	FALLOW1			
MEANS	69.6347	76.5489	75.9042			
COVARS LINE	1 VALUES		20.2562	22.2764	17.1410	
COVARS LINE	2 VALUES		22.2764	37.4409	28.5156	
COVARS LINE	3 VALUES		17.1410	28.5156	32.8853	
CLASS NUMBER	16	NAME	WOODS			
MEANS	40.2256	29.3293	74.9268			
COVARS LINE	1 VALUES		6.06497	6.52329	5.35804	
COVARS LINE	2 VALUES		6.52329	12.1477	8.34122	
COVARS LINE	3 VALUES		5.25804	8.34122	20.1778	
CLASS NUMBER	17	NAME	FOREST			
MEANS	40.0754	29.7626	57.3606			
COVARS LINE	1 VALUES		6.11949	5.42821	4.94702	
COVARS LINE	2 VALUES		5.42821	10.6060	7.11496	
COVARS LINE	3 VALUES		4.94702	7.11496	29.9691	
CLASS NUMBER	18	NAME	built_up			
MEANS	52.9974	45.1082	38.2533			
COVARS LINE	1 VALUES		13.8393	14.5175	10.9585	
COVARS LINE	2 VALUES		14.5175	20.9935	15.9646	
COVARS LINE	3 VALUES		10.9585	15.9646	32.9068	
CLASS NUMBER	19	NAME	BEACH			
MEANS	72.1475	77.8571	68.8617			
COVARS LINE	1 VALUES		19.3879	28.2837	26.0988	
COVARS LINE	2 VALUES		28.2837	49.9571	43.7918	
COVARS LINE	3 VALUES		26.0988	43.7918	66.9675	

END

Fthmss.sta

Saved statistics file for the MSS image classification on the intensive moorland area without urban use or arable farming.

```
/*          GEMSTONE  save file
/*
TYPE CL.STAT
PARAMS CLASSES     19    IMAGES          3
LOWER33       21      9
UPPER 77      85      121
CLASS NUMBER       2      NAME RESR
MEANS    36.7415  25.8305          16.2839
COVARS LINE   1 VALUES             6.25959        2.55367        1.60946
COVARS LINE   2 VALUES             2.55367        2.58141        1.26847
COVARS LINE   3 VALUES             1.60946        1.26847        5.33892
CLASS NUMBER       3      NAME SHALLOW_WATER
MEANS    48.2186  37.4014          17.2115
COVARS LINE   1 VALUES             21.7693        31.6721        18.3623
COVARS LINE   2 VALUES             31.6721        54.8354        37.9617
COVARS LINE   3 VALUES             18.3623        37.9617        64.5252
CLASS NUMBER       4      NAME         GOLFGRASS
MEANS    49.0984  37.6197          110.410
COVARS LINE   1 VALUES             8.16846        10.5639        -10.4448
COVARS LINE   2 VALUES             10.5639        21.4589        -20.0494
COVARS LINE   3 VALUES             -10.4448       -20.0494       54.4750
CLASS NUMBER       5      NAME          PASTURE
MEANS    46.3963  34.8720          112.604
COVARS LINE   1 VALUES             5.81218        6.06888        -5.72145
COVARS LINE   2 VALUES             6.06888        10.9408        -11.8742
COVARS LINE   3 VALUES             -5.72145       -11.8742       128.811
CLASS NUMBER       10     NAME         DARKMOOR
MEANS    34.5643  27.3000          47.5107
COVARS LINE   1 VALUES             1.73162        1.28433        3.08228E-1
COVARS LINE   2 VALUES             1.28433        2.31719        9.68225E-1
COVARS LINE   3 VALUES           3.08228E-1     9.68225E-1       6.34264
CLASS NUMBER       11     NAME         LIGHTMOOR
MEANS    43.1840  38.8143          65.8126
COVARS LINE   1 VALUES             11.3937        12.7838        25.0599
COVARS LINE   2 VALUES             12.7838        19.2416        35.1373
COVARS LINE   3 VALUES             25.0599        35.1373        85.5116
```

CLASS NUMBER	12	NAME	SNOWMOOR		
MEANS	63.6591 51.8864		55.9621		
COVARS LINE	1 VALUES		25.7398	21.0067	2.18418
COVARS LINE	2 VALUES		21.0067	20.2068	3.67764
COVARS LINE	3 VALUES		2.18418	3.67764	21.6124
CLASS NUMBER	13	NAME	MOOREDGE		
MEANS	61.7702 63.3150		90.5413		
COVARS LINE	1 VALUES		9.83625	10.8373	5.55659
COVARS LINE	2 VALUES		10.8373	19.0909	3.44732
COVARS LINE	3 VALUES		5.55659	3.44732	27.3080
CLASS NUMBER	14	NAME	WETLAND		
MEANS	37.8961 28.9610		29.2727		
COVARS LINE	1 VALUES		4.74253	3.74924	9.89376E-1
COVARS LINE	2 VALUES		3.74924	9.02448	12.2704
COVARS LINE	3 VALUES		9.89376E-1	12.2704	36.8217
CLASS NUMBER	15	NAME	WETMOOR		
MEANS	45.8564 37.8785		48.2541		
COVARS LINE	1 VALUES		2.99601	1.86661	2.08635
COVARS LINE	2 VALUES		1.86661	4.17318	5.59457
COVARS LINE	3 VALUES		2.08635	5.59457	19.3389

END

Semss.sta

Saved statistics file for the MSS image classification, showing the full information on the statistics of all spectral classes.

```
/*          GEMSTONE  save file
/*
/*      File was created at 18:02:12 on 16th May 1989
/*
TYPE  CL.STAT
NAME  SAVED STATISTICS WITH 17 AREAS 16-05-89
PARAMS  CLASSES      19       IMAGES        3
LOWER33        21       9
UPPER 77       85       121
CLASS  NUMBER        1        NAME  SEA
MEANS     38.2623  24.1452              11.2237
COVARS  LINE   1 VALUES                 8.25821          3.55073          4.32042E-1
COVARS  LINE   2 VALUES                 3.55073          2.92186          3.08797E-1
COVARS  LINE   3 VALUES              4.32042E-1       3.08797E-1          7.33388E-1
CLASS  NUMBER        2        NAME             RESR
MEANS     36.7415  25.8305              16.2839
COVARS  LINE   1 VALUES                 6.25959          2.55367             1.60946
COVARS  LINE   2 VALUES                 2.55367          2.58141             1.26847
COVARS  LINE   3 VALUES                 1.60946          1.26847             5.33892
CLASS  NUMBER        3        NAME  SHALLOW_WATER
MEANS     48.2186  37.4014              17.2115
COVARS  LINE   1 VALUES                 21.7693          31.6721             18.3623
COVARS  LINE   2 VALUES                 31.6721          54.8354             37.9617
COVARS  LINE   3 VALUES                 18.3623          37.9617             64.5252
CLASS  NUMBER        4        NAME          GOLFGRASS
MEANS     49.0984  37.6197              110.410
COVARS  LINE   1 VALUES                 8.16846          10.5639            -10.4448
COVARS  LINE   2 VALUES                 10.5639          21.4589            -20.0494
COVARS  LINE   3 VALUES                -10.4448         -20.0494             54.4750
CLASS  NUMBER        5        NAME            PASTURE
MEANS     46.3963  34.8720              112.604
COVARS  LINE   1 VALUES                 5.81218          6.06888            -5.72145
COVARS  LINE   2 VALUES                 6.06888          10.9408            -11.8742
COVARS  LINE   3 VALUES                -5.72145         -11.8742             128.811
CLASS  NUMBER        6        NAME             CEREAL
MEANS     54.2759  45.4483              83.5862
```

COVARS LINE 1 VALUES		5.78579	5.68657	9.61413
COVARS LINE 2 VALUES		5.68657	12.1438	7.20015E-1
COVARS LINE 3 VALUES		9.61413	7.20015E-1	80.8291
CLASS NUMBER 7	NAME	SBARLEY		
MEANS 57.5758 58.8485		58.8182		
COVARS LINE 1 VALUES		7.75968	6.46626	4.18073
COVARS LINE 2 VALUES		6.46626	12.43	6.09068E-1
COVARS LINE 3 VALUES		4.18073	6.09068E-1	14.9369
CLASS NUMBER 8	NAME	ROOTS		
MEANS 53.3913 52.3913		50.1739		
COVARS LINE 1 VALUES		6.06436	6.10784	5.36685
COVARS LINE 2 VALUES		6.10784	10.3252	3.62772
COVARS LINE 3 VALUES		5.36685	3.62772	12.1438
CLASS NUMBER 9	NAME	FALLOW1		
MEANS 69.6347 76.5489		75.9042		
COVARS LINE 1 VALUES		20.2562	22.2764	17.1410
COVARS LINE 2 VALUES		22.2764	37.4409	28.5156
COVARS LINE 3 VALUES		17.1410	28.5156	32.8853
CLASS NUMBER 10	NAME	DARKMOOR		
MEANS 34.5643 27.3000		47.5107		
COVARS LINE 1 VALUES		2.73162	1.28433	3.08228E-1
COVARS LINE 2 VALUES		1.28433	2.31719	9.68225E-1
COVARS LINE 3 VALUES		3.08228E-1	9.68225E-1	6.34264
CLASS NUMBER 11	NAME	LIGHTMOOR		
MEANS 43.1840 38.8143		65.8126		
COVARS LINE 1 VALUES		11.3937	12.7838	25.0599
COVARS LINE 2 VALUES		12.7838	19.2416	35.1373
COVARS LINE 3 VALUES		25.0599	35.1373	85.5116
CLASS NUMBER 12	NAME	SNOWMOOR		
MEANS 63.6591 51.8864		55.9621		
COVARS LINE 1 VALUES		25.7398	21.0067	2.18418
COVARS LINE 2 VALUES		21.0067	20.2068	3.67764
COVARS LINE 3 VALUES		2.18418	3.67764	21.6124
CLASS NUMBER 13	NAME	MOOREDGE		
MEANS 61.7702 63.3150		90.5413		
COVARS LINE 1 VALUES		9.83625	10.8373	5.55659
COVARS LINE 2 VALUES		10.8373	19.0909	3.44732
COVARS LINE 3 VALUES		5.55659	3.44732	27.3080
CLASS NUMBER 14	NAME	WETLAND		
MEANS 37.8961 28.9610		29.2727		
COVARS LINE 1 VALUES		4.74253	3.74924	9.89376E-1

COVARS LINE	2 VALUES			3.74924	9.02448	12.2704
COVARS LINE	3 VALUES			9.89376E-1	12.2704	36.8217
CLASS NUMBER	15	NAME	WETMOOR			
MEANS	45.8564	37.8785		48.2541		
COVARS LINE	1 VALUES			2.99601	1.86661	2.08635
COVARS LINE	2 VALUES			1.86661	4.17318	5.59457
COVARS LINE	3 VALUES			2.08635	5.59457	19.3389
CLASS NUMBER	16	NAME	WOODS			
MEANS	40.2256	29.3293		74.9268		
COVARS LINE	1 VALUES			6.06497	6.52329	5.35804
COVARS LINE	2 VALUES			6.52329	12.1477	8.34122
COVARS LINE	3 VALUES			5.25804	8.34122	20.1778
CLASS NUMBER	17	NAME	FOREST			
MEANS	40.0754	29.7626		57.3606		
COVARS LINE	1 VALUES			6.11949	5.42821	4.94702
COVARS LINE	2 VALUES			5.42821	10.6060	7.11496
COVARS LINE	3 VALUES			4.94702	7.11496	29.9691
CLASS NUMBER	18	NAME	built_up			
MEANS	52.9974	45.1082		38.2533		
COVARS LINE	1 VALUES			13.8393	14.5175	10.9585
COVARS LINE	2 VALUES			14.5175	20.9935	15.9646
COVARS LINE	3 VALUES			10.9585	15.9646	32.9068
CLASS NUMBER	19	NAME	BEACH			
MEANS	72.1475	77.8571		68.8617		
COVARS LINE	1 VALUES			19.3879	28.2837	26.0988
COVARS LINE	2 VALUES			28.2837	49.9571	43.7918
COVARS LINE	3 VALUES			26.0988	43.7918	66.9675

END

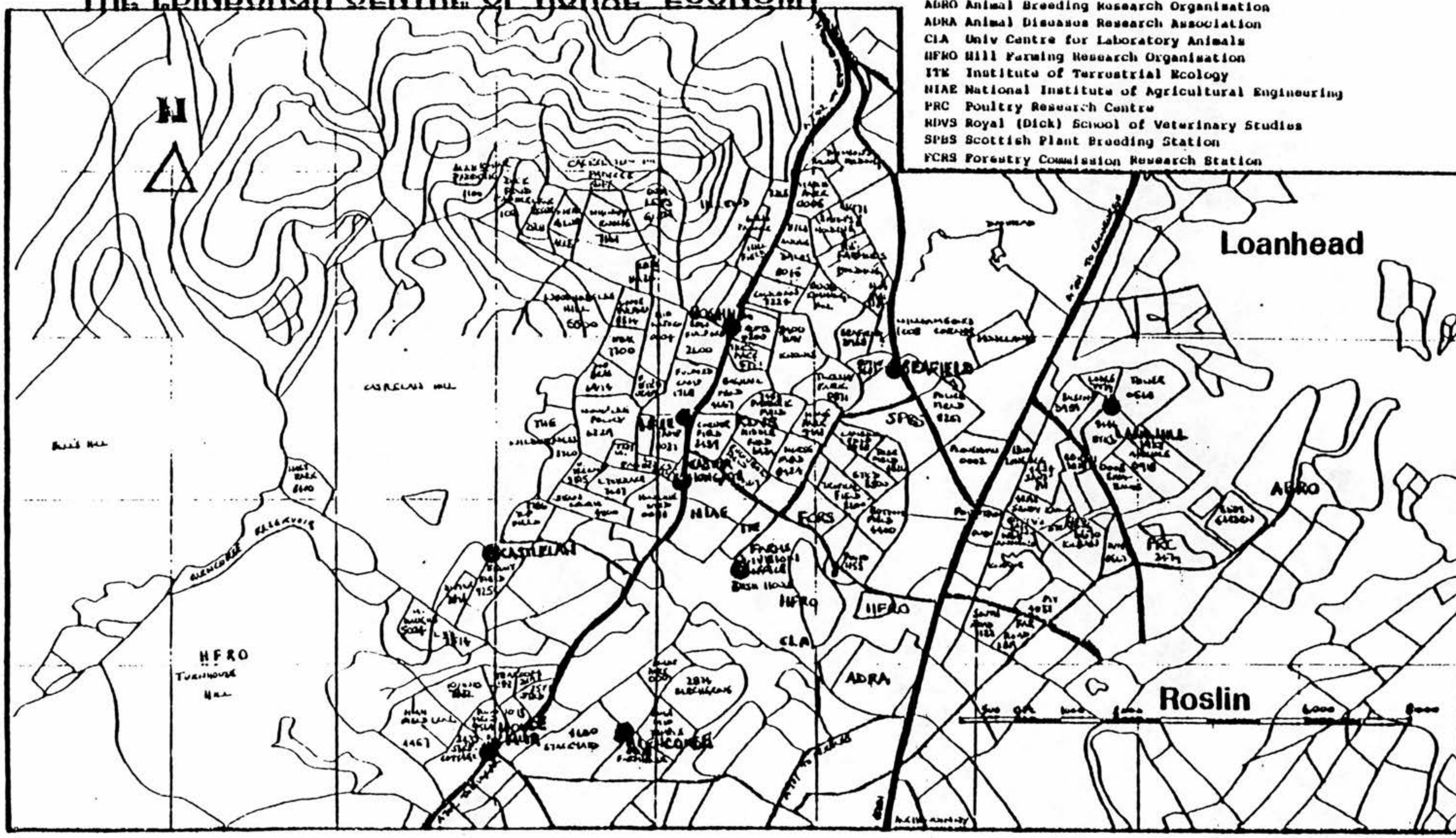
APPENDIX 6

Farm Cropping Plan Record Data and the Transformed Maps

BUSH ESTATE

THE EDINBURGH CENTRE OF RURAL ECONOMY

ABRO Animal Breeding Research Organisation
ADRA Animal Diseases Research Association
CLA Univ Centre for Laboratory Animals
HFRO Hill Farming Research Organisation
ITE Institute of Terrestrial Ecology
NIAE National Institute of Agricultural Engineering
PRC Poultry Research Centre
RDVS Royal (Dick) School of Veterinary Studies
SPBS Scottish Plant Breeding Station
FCRS Forestry Commission Research Station



Areas in hectares										
	0001 - 9.67	0002 - 9.67		0004 - 2.87	0004 - 6.43	0005 - 7.39	0005 - 6.67	0006 - 12.10	0020 - 1.49	0037 - 9.66
	0038 - 8.44	0061 - 6.97	0069 - 2.90	0080 - 2.88	0688 - 6.75	0208 - 3.13	0568 - 11.21	0600 - 2.35	0871 - 8.36	0918 - 7.46
	1073 - 1.58	1122 - 3.77	1155 - 0.62	1300 - 6.10	1651 - 2.35	1709 - 1.58	1768 - 6.96	1786 - 5.65	1865 - 6.18	1927 - 4.38
	1971 - 1.89	2200 - 3.92	2437 - 0.51	2474 - 14.40	2483 - 1.38	2493 - 3.16	2579 - 2.86	2600 - 7.54	2638 - 8.39	2733 - 3.24
		2819 - 3.16	2868 - 4.19	2874 - 9.89	2968 - 4.78	3439 - 6.70	3560 - 5.08	3687 - 2.01	3724 - 2.47	3727 - 3.98
	3760 - 1.55	3867 - 2.01	4100 - 1.81	4291 - 5.60	4400 - 6.41	4424 - 9.72		4457 - 7.74	4526 - 3.90	4650 - 12.69
	4663 - 5.87	4667 - 7.80	4800 - 6.38	4837 - 5.14	5024 - 4.04	5127 - 2.43	5280 - 0.28	5319 - 5.42	5515 - 4.13	5589 - 6.40
	5695 - 8.97	5707 - 3.43	5829 - 1.48	5959 - 5.30	6066 - 5.70	6200 - 5.67	6229 - 7.13	6266 - 2.34	6438 - 5.37	6474 - 5.19
	6670 - 7.26	7155 - 5.99	7161 - 12.99	7224 - 4.90	7265 - 7.36	7437 - 8.51	7455 - 5.99	7514 - 3.13	7607 - 4.57	7700 - 4.14
	7727 - 2.64	7843 - 3.29	7882 - 7.70	7974 - 1.91	8045 - 5.62	8251 - 5.50	8314 - 4.08	8400 - 6.29	8424 - 5.39	8436 - 1.81

Field Name	Ha	1984 Crop	1985 Crop	1986 Crop	1987 Crop	Variety/ Stocking	Fertiliser Input (kg/ha) N	P	K
BOGHALL/EASTER HOWGATE (Arable)									
Kimming Hill	12.90	S Barley u/s	Grass 1	Grass 2	Potatoes	Piper, Wilja Squire	140	140	190
Hay Knowes	11.13	Roots	S Barley	S Barley u/s	Grass 1	Silage 2 cuts	280	45	90
March Park	7.39	Cereal Trial	W Barley	W Barley	W Barley	Pirate	170	65	65
Anchordales	2.72 5.61	Triticale NLT Grass	W Barley NLT Trials	W Barley NLT Trials	W Barley NLT Trials	Pirate NLT Trials	180	65	65
Thomson's Holding	2.35	S Barley	S Barley	W Barley	4.8 ha W Barley	Igri	170	65	65
Low Terrace	4.57	W Wheat	S Barley	S Barley	S Barley u/s	Golf	100	50	50
Jean Lowrie	6.38	S Barley	S Barley Trial	Roots	S Barley	Klaxon	80	40	40
Smith's Holding	1.89	S Barley	W Barley	W Barley	W Barley	Pirate	170	65	65
LL/House Park	6.40	Potatoes	W Wheat	S Barley	W Barley	Igri	160	60	60
Horse Park	3.43	Potatoes	W Wheat	S Barley	W Barley	Igri	170	65	65
Farmer's Holding	2.55	S Barley	W Barley	W Barley	W Barley	Pirate	170	60	60
Lower Fulford	7.54	W Barley	Potatoes	W Wheat W Barley	S Barley	Triumph	80	40	40
Seafield	4.50	S Barley	Potatoes	W Wheat	S Barley Trials	Golf	100	50	50
Hill Field	7.36	W Barley	W Barley	S Barley Potatoes	Swedes	Ruta Otofte Trials	100	160	160B
No 4 Holding	2.47	S Barley	W Barley	S Barley	Potatoes	Trials			
Stuart's Field	2.4	Grass	Grass	Grass		see Thomson's Holding			

Field Name	Ha	1984 Crop	1985 Crop	1986 Crop	1987 Crop	Variety/ Stocking	Fertiliser Input (kg/ha)		
HOUSE O'MUIR/ GLENCORSE									
Shepherd's Cottage High Field	8.40) 1.60)	Grass 4 Cattle	Grass 5 Sheep	Grass 6 Cattle	Grass 7 Sheep	150 GF ewes	300	30	30
Knowes	7.79	Grass 2	Potatoes	S Barley	W Wheat	Longbow	160	84	84
Beechgrove	9.89	Grass 1	Grass 2	Grass 3	Grass 1	Trials	92	120	120
Mid Temple	6.97	W Wheat	W Wheat	S Barley	Grass 1	Silage 2 cuts	280	60	110
Pond	5.00	Potatoes	W Wheat	S Barley	S Barley	Natasha	85	43	43
Tearoom	6.29	Grass 3 Sheep	Grass 4 Cattle	Grass 5 Sheep	Grass 6 Cattle	34 finishers	260	25	25
Farmhouse	8.44	Grass 3	Grass 4	Grass 5	W Wheat	Longbow	170	74	74
House o'Muir Stackyard	2.86	Grass 3 Sheep	Grass 4 Cattle	Grass 5 Sheep	Grass 6 Cattle	16 finishers	260	25	25
Glencorse Stackyard	2.00	Grass 3 Sheep	Grass 4 Sheep	Grass 5 Sheep	Grass 6 Sheep	50 Suffolk hoggs	260	30	30
	5.00	W Wheat	W Wheat	S Barley	Grass 1	Silage 2 cuts	280	60	110
BOGHALL/EASTER HOWGATE									
GRASS AND ARABLE									
Mid Fulford	8.98	Grass 2	Grass 3	Grass 4	Grass 6	Silage 1 cut 35 GF ewes	300	51	95
Woodhouselee Camp	4.40	W Wheat	Potatoes	S Barley	Grass 1	Silage 2 cuts	280	45	90
Crofts	5.67	W Barley	3.67 NLT 2 W Barley	3.67 NLT 2 W Wheat	1 Trials 1.2 W Wheat 3.4 S Barley	 Longbow Triumph	 190 80	 65 40	 65 40
Fulford Camp	6.96	Grass 4	S Barley	Potatoes	W Wheat	Longbow	180	65	65
Howgate Stackyard	6.75	Grass 2	Grass 3	Potatoes	W Wheat	Slepjner	160	74	74
Bothy	2.01	Barley	S Barley	S Barley	W Barley	Igri	170	65	65
Cowloan	4.89	Barley	S Barley	S Barley	S Barley	Triumph	80	40	90
Upper Terrace	4.13	Grass 3	Grass 4	Grass 5	Grass 6	Silage 2 cuts	280	45	90

Boghall Hill	Ha	1984	1985	1986	1987	Variety/ Stocking	Fertiliser Input kg/ha		
Whinny Knowe	10.00	BF Lambing 15 S Cows/calves	100 BF Ewes/ twins	40 HxF Cows	BF Sheep	70 ewes/twins	120	30	30
Leips Glen	20.93	120 BF Ewes/ Twins	SP Calving Cows/calves	100 BF Sheep	HxF cows	35 Sp calving cows/calves	140	30	30
Near Reseed	8.66	15 S HxF Cows/ Calves	12 S Calving Cows/calves	50 BF Sheep	HXF cows	15 Sp Calving cows/calves	120	30	30
Far Reseed	4.19	10 S Calving HxF Cows	40 BF Ewes & twins	10 HxF Cows	BF Sheep	40 ewes/twins	120	30	30
Duckpond Reseed Duckpont Hill	15.00	25 S Calving HxF Cows/calves	12 S Calving Cows/calves	20 HxF Cows	BF Sheep	60 ewes/singles	120	30	30
Leips Field	1.80	S Calving cows	5 S Calving Cows/calves	12 BF Ewes	HxF Cows	5 Sp Calving cows	140	30	30
Allermuir Paddock		120 BF Singles	160 BF Ewes & Singles	160 BF Ewes 80 BF Hoggs	BF Ewes	140 Ewes/Singles	140	30	30
Hill Field Paddock	80	60 BF Singles				100 Hoggs			
Caerketton Paddock		80 BF Ewe Hoggs	80 BF Ewe Hoggs						
CASTLELAW HILL									
St Catherines Park	5.6	50 BF Ewes/twins	70 Ewes/Twins	BF Ewes	BF Ewes	70 Ewes/Mixed	100	30	30
Front Green	20	100 BF Ewes/twins	100 BF Ewes/twins	BF Ewes	BF Ewes	100 Ewes/Twins	76	30	30
Open Hill	280	380 BF Ewes/lmbs 180 BF Hoggs	380 Ewes/lambs 180 BF Hoggs	BF Ewes 70 HxF cows	BF Ewes HxF cows	420 Ewes/singlcs 200 Hoggs 40 dry cows			
Wilderness	4	60 HxF Cows	60 HxF Cows	BF Ewes HxF Cows	HxF Cows	6 Cull cows	100	30	30

PERMANENT PASTURE

	Ha	1984	1985	1986	1987	Variety/ Stocking	Fertiliser Input		
Upper Fulford	4.08	12 Cows/Calves	60 GF Ewes	Silage/ 30 Cattle	GF Sheep	60 ewes/ lambs	280	30	30
Neuk	4.14	14 Cows/Calves	60 GF Ewes	30 Cattle	GF Sheep	60 ewes/ lambs	280	30	30
Doo Brae	5.19	16 Cows/Calves	60 GF Ewes/ lambs	30 Cattle	GF Sheep	60 ewes/ lambs	280	30	30
Upper Paddock	2.64	60 Suffolk Ewes	12 Cows		Suffolks	50 Tup hoggs	255	30	30
Lower Paddock	1.49	& Lambs	Sfk Ewe Lambs	Suffolks	H X F cows	5 Sp Calves	255	30	30
Upper Haughs	4.04	Grass 1 40 Ewes/Lambs	50 Store ctle	GF Sheep	Cattle	17 finishers	215	22	22
Lower Haughs	3.12	40 GF Ewes/ Lambs	Grass/Hay	GF Sheep	Cattle	17 finishers	215	22	22
West Park	6.29	80 GF Ewes/ Lambs	20 Aut.Cows/ Calves	GF Sheep	Cattle	37 finishers	300	30	30
Fulford Stackyard	2.98	Suffolk Ewes	Suffolk Ewes	Suffolks	Suffolks	100 ewes	280	30	30
Woodhouseles Plcy	3.20	12 Cows/Calves	Sfk Ewe Hoggs	Cattle	Suffolks	40 ewes	250	30	30
Upper Lambings	3.20	10 Cows/Calves	10 Cows/Calves	Cattle	Cattle	10 sp calving	280	30	30
Pony Paddocks	1.50	4 Bulls	4 Bulls	Cattle	Suffolks	10 Rams	255	30	30
Tup Field	5.65	Hay	Hay	Silage	Silage	1 cut	256	43	87
Front Field	7.30 1.80	BF Ewes/ Cattle	BF Ewes/ Cattle	BF Sheep	Cattle	25 sp calving cows/calves	230	30	30
Dipper	3.29	Rape	Reseed/Lambs	BF Sheep	BF Sheep	30 ewes/twins	255	30	30

ARABLE

O.S. Field No.	Name	Ha	1986 Crop	1987 Crop	Variety/ Stocking	Fertiliser Input (kg/ha)
4044	Low Trough Moss	12.8	S Barley	S Barley	Golf	100 : 50 : 50
4300	West Dean Field	6.2	W Barley	S Barley u/s	Golf	100 : 50 : 50
6368	Doctor's Dtrip	7.0	W Barley	Potatoes/Swedes	$VTSC_2$+ Ruta Otofte	
8972	Doctors	4.0	Roots	S Barley	Klaxon	70 : 35 : 35
8000	Strip	3.6	S Barley	S Barley u/s	Golf	100 : 50 : 50
1400	Castle Park	5.4	Grass 1	GF Sheep	70 ewes/lambs	250 : 30 : 30
3378	Lodge Park	4.8	Potatoes	S Barley	Klaxon	90 : 50 : 50
6400	Tympany	12.0	Grass	Silage	2 cuts	240 : 80 : 110
0080	Speargate	10.5	S Barley	Grass	Hay	200 : 60 : 90
				S Barley u/s	Golf	80 : 40 : 40
0031	Long Croft	9.8	S Barley	S Barley	Klaxon	110 : 50 : 50
6025	Pit	8.0	Grass	Silage	Silage 1 cut	220 : 60 : 90
7900	Happen Burn	10.5	Grass	Silage	Silage 1 cut	220 : 60 : 90
9852	Steading Field	7.4	S Barley	S Barley	Golf	110 : 45 : 45
LONG LEY						
5200	Policemans	5.0	W Barley	S Barley u/s	Corgi	90 : 45 : 45
2800	Sikes Field	4.8	Sheep	Cattle	72 P.F. calves	250 : 30 : 30
0063	High Trough Moss	4.2	Hay	Cattle	47 ch x calves 9 mth	230 : 30 : 30
0084	Silverburn Field	4.2	Hay	Cattle	43 H x calves 9 mth	230 : 30 : 30
5617	Brae	3.0	Silage	Silage	2 cuts	230 : 90 : 120
7215	Rural	4.0	Silage	Silage	2 cuts	230 : 90 : 120
7649	Garage	4.4	Cattle	G.F.Sheep	50 ewes/lambs	220 : 30 : 30

CARSEWELL FARM Continued..........

PERMANENT PASTURE

O.S. Field No.	Name	Ha	1986 Crop	1987 Crop	Variety/ Stocking	Fertiliser Input (kg/ha)
5245	Saw Mill Field	3.0	Cattle	G.F. Sheep	35 ewes/lambs	220 : 30 : 30
5600	Low Pond	5.0	Sheep	5-crop B.F. Sheep	55 ewes/lambs	180 : 30 : 30
4665	Hurley	5.0	Sheep	5-crop B.F. Sheep	50 ewes/lambs	180 : 30 : 30
8826	Happen Burn Bank	1.6	Sheep	5-crop B.F. Sheep	15 ewes/lambs	200 : 30 : 30
7779	Doctors House	1.6	Sheep	Sheep	Tups	200 : 30 : 30

ROUGH

1800	East Dean Field	3.0	Sheep	G.F. Sheep	40 ewes/lambs	120 : 20 : 20
0005	Horse Park	2.0	Sheep	G.F. Sheep	25 ewes/lambs	120 : 20 : 20

SUMMARY

	ha
Spring Barley	38.8
Undersown Barley	20.3
Swedes	4
Potatoes	3
Hay	5
Silage	37.5
320 ewes/lambs	31
160 cattle	13.2
	152.8

RENTED LAND

MORTONHALL	Ha	1984 Crop	1985 Crop	1986 Crop	1987 Crop	Variety/ Stocking	Fertiliser Input (kg/ha)		
Roundel	8.40	W Barley	W Barley	W Barley	W Barley	Magic	170	65	65
Kennel Park	6.00	Potatoes	W Wheat	S Barley	W Barley	Igri	170	65	65
Middle Park	3.50	Potatoes	W Wheat	S Barley	W Barley	Igri	170	65	65
Frogston Road	5.60	W Wheat	W Wheat	W Barley	W Barley	Magic	170	65	65
EASTER BUSH									
Paddock Field	5.9	Grass	Grass	Potatoes	S Barley u/s	Natasha	66	33	33
Policemans							100	40	40
LANGHILL									
House Field	3.8	Grass	Grass	W Wheat	S Barley	Klaxon	90	45	45
Monklands	11.0	Grass	S Barley	S Barley	Grass	Direct reseed			
Anniesknowe	6.8	Grass	Grass	Grass	W Wheat	Brock	180	67	67
PRC	4	Grass	Grass	Grass	S Barley u/s	Corgi	66	33	33

BUSH CEREAL TRIALS CENTRE : 1987.

WINTER BARLEY TRIAL SITE :

GRID REF. : NT 252653

ELEVATION : 190m

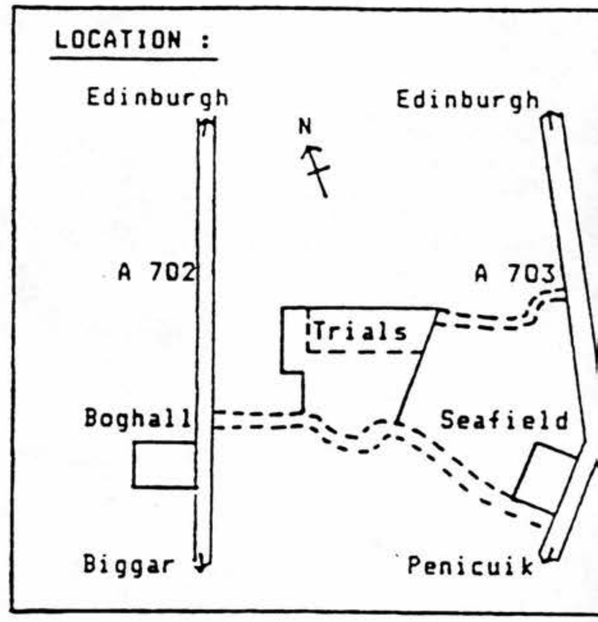
SOIL SERIES : DUNCRAHILL

SOIL TYPE : SANDY CLAY LOAM

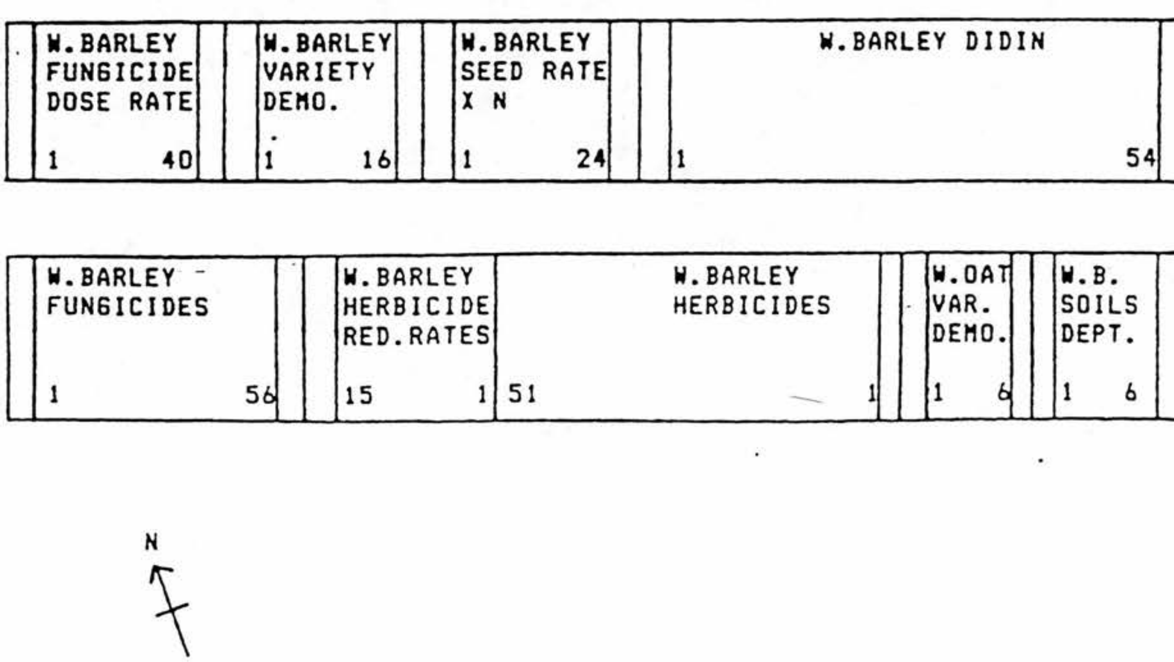
PREVIOUS CROPPING : 86-GRASS
85-GRASS
84-S.BARLEY
83-ROOTS
82-W.WHEAT

SOIL ANALYSIS : pH - 5.9
P - MOD
K - MOD/LOW
Mg- MOD

FIELD NAME - KIMMING HILL

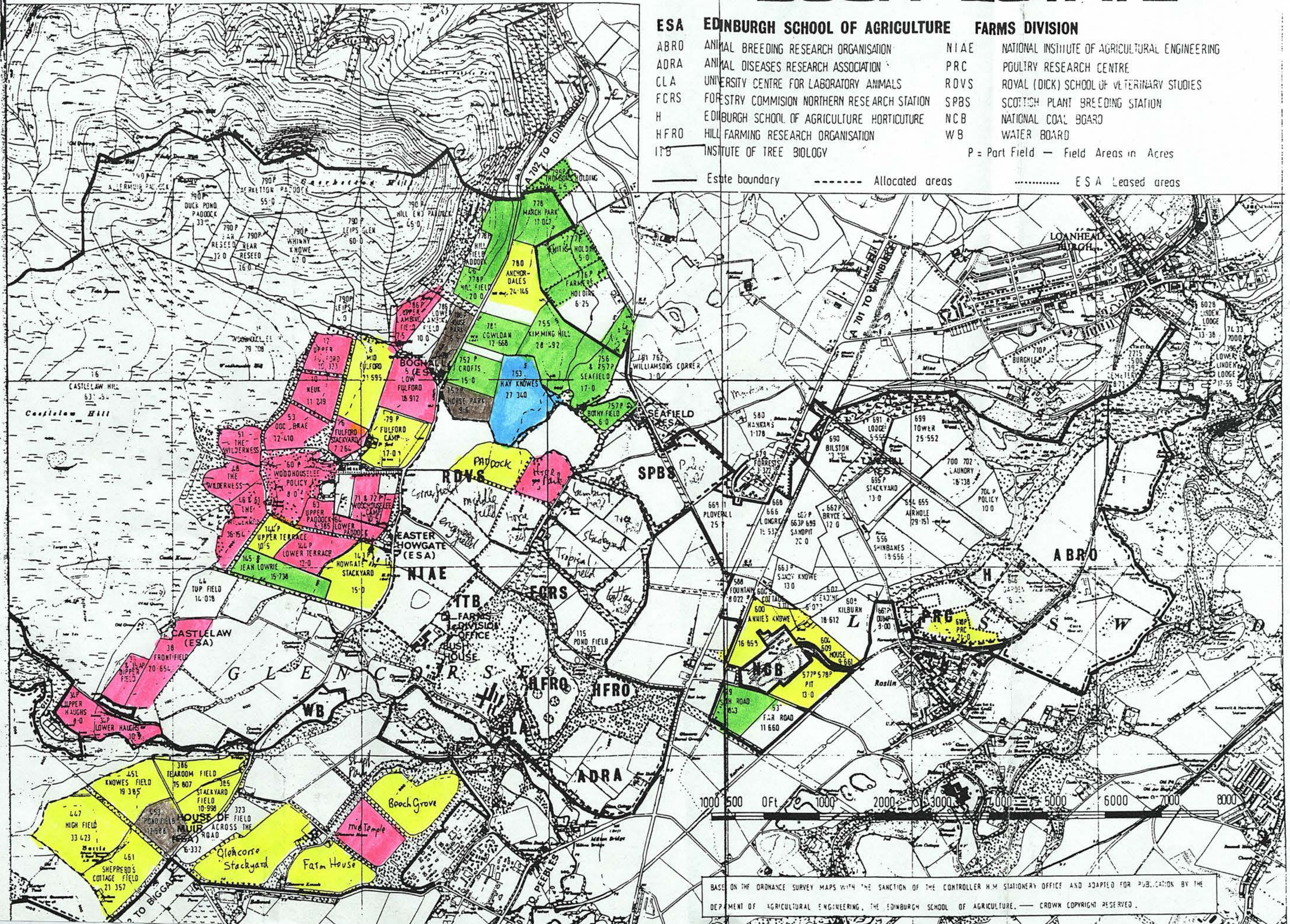


FIELD LAYOUT :



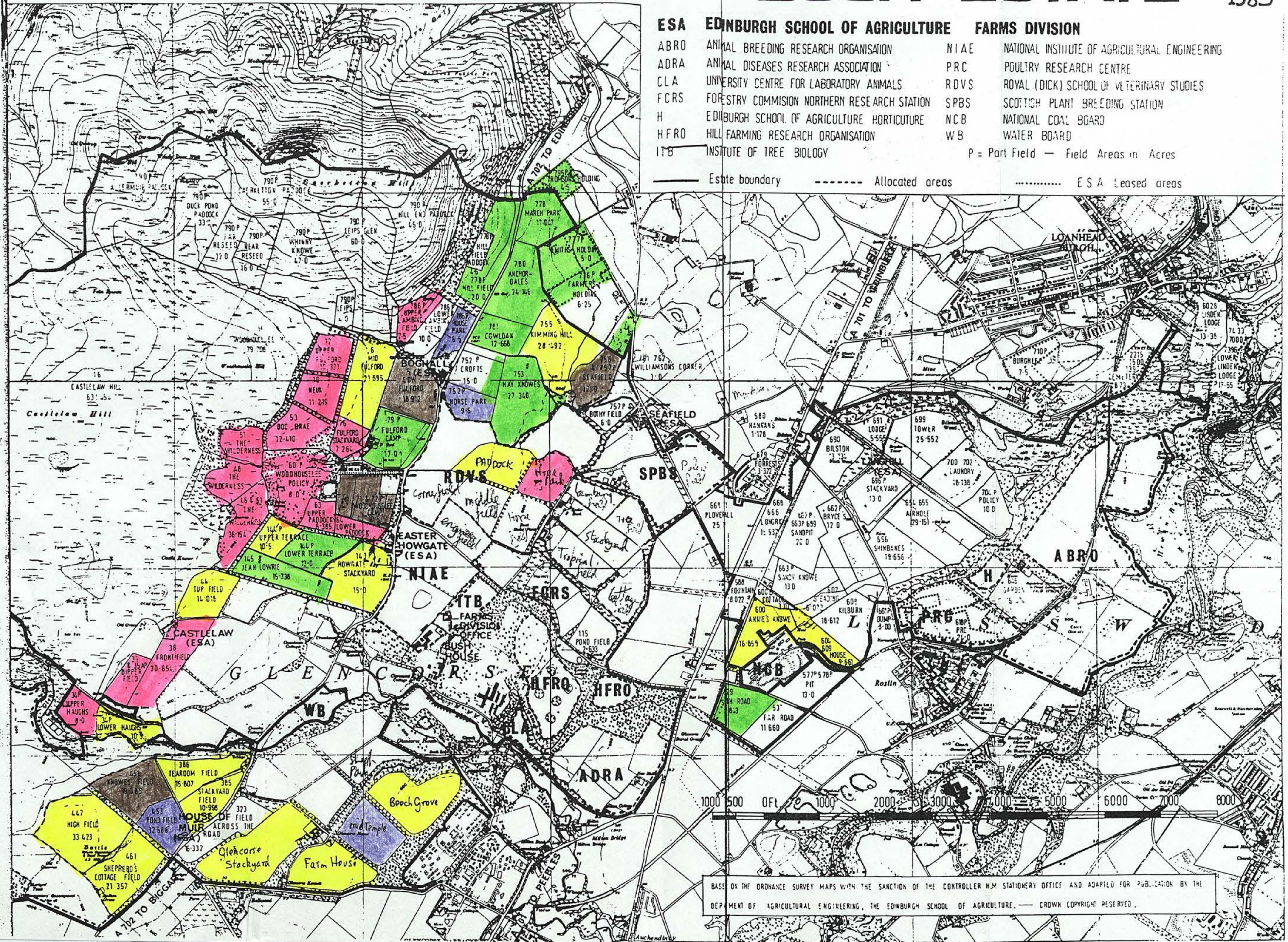
CENTRE OF RURAL ECONOMY — BUSH ESTATE

1984



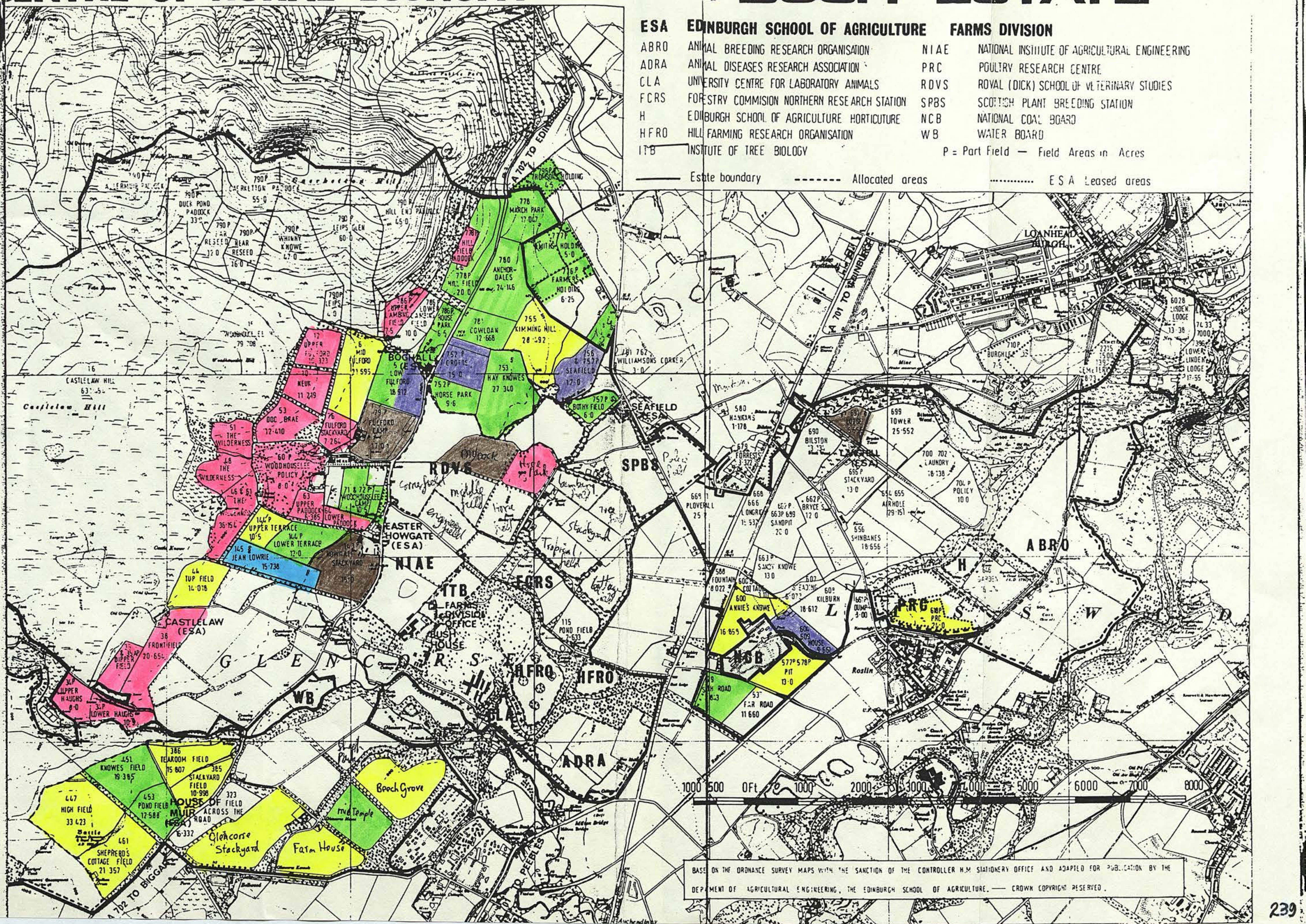
CENTRE OF RURAL ECONOMY — BUSH ESTATE

1985



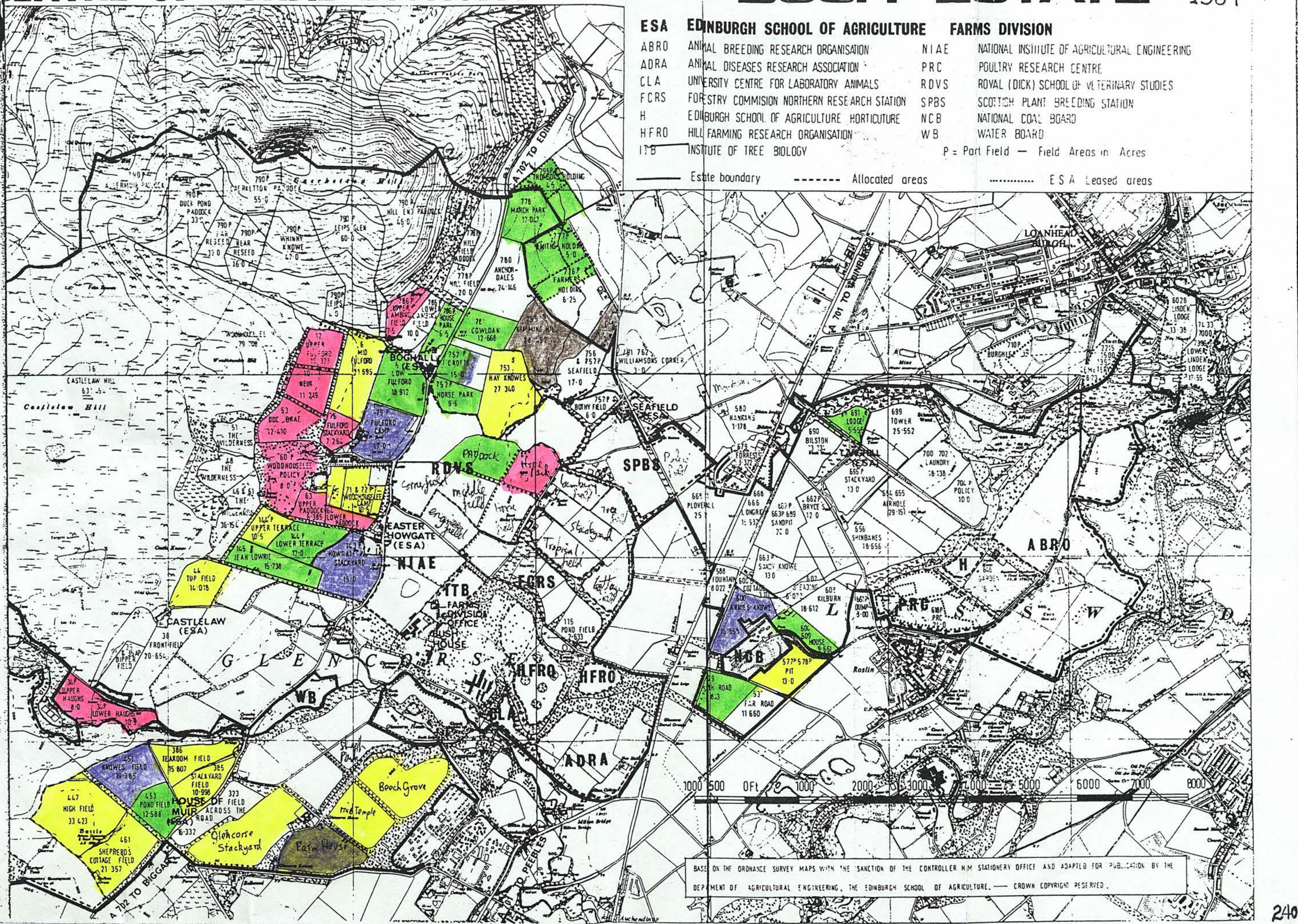
1986

CENTRE OF RURAL ECONOMY — BUSH ESTATE



CENTRE OF RURAL ECONOMY — BUSH ESTATE

1987



APPENDIX 7

Figures and Plates Showing the Segmented Classification

This appendix shows an example of image segmentation for the TM image classification. To reduce the confusion between built-up areas and moorlands in the classification of the TM image, segmentation of the image was applied. The whole image (Plate (a)) was delineated into an intensive moorland area and the rest of the area without rough moors, according to the ground features and the characteristics of the image scene (as shown in Figure (a)). Statistics generated for the TM image classification were also compiled into two groups. Each was used in different parts of the image (Details in Appendix 5). The classified results of separate parts of the image were then copied into a whole image and the pixel location on each subscene remained unchanged (Plate (b)). These classified image files with information on spectral classes were further recoded into new groups representing feature classes using the RECODEIMAGE modules of the GEMSTONE-35 to ARC/INFO interface. Plate (c) shows the recoded classification results with each information class annotated. By defining the same set of information classes for the two images of different dates, it helped to meet the need for the comparison of classification results.

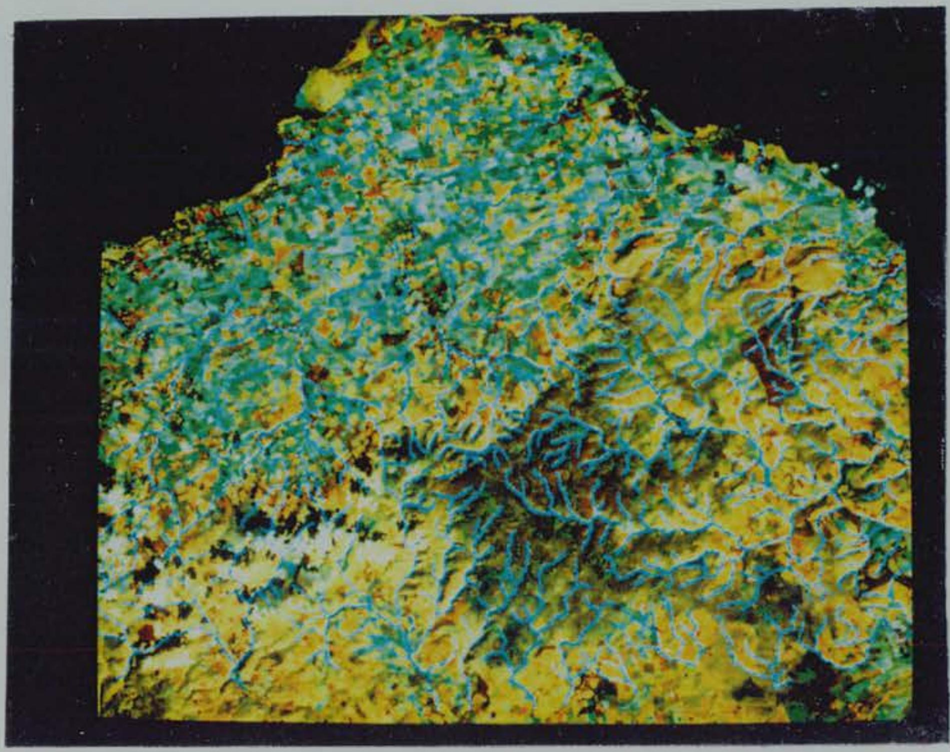


Plate (a). Colour composite of TM Bands 3(blue), 4(red) and 5(green) of the Lammermuir Hills and adjacent lowlands in South-East Scotland (14 September 1986).

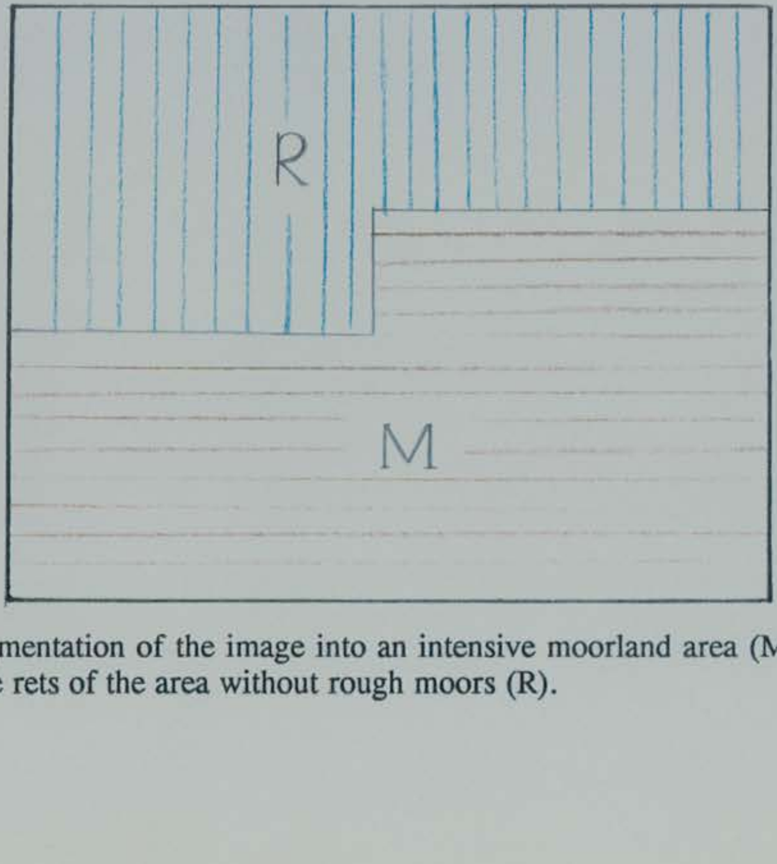


Figure (a). Segmentation of the image into an intensive moorland area (M) and the rets of the area without rough moors (R).

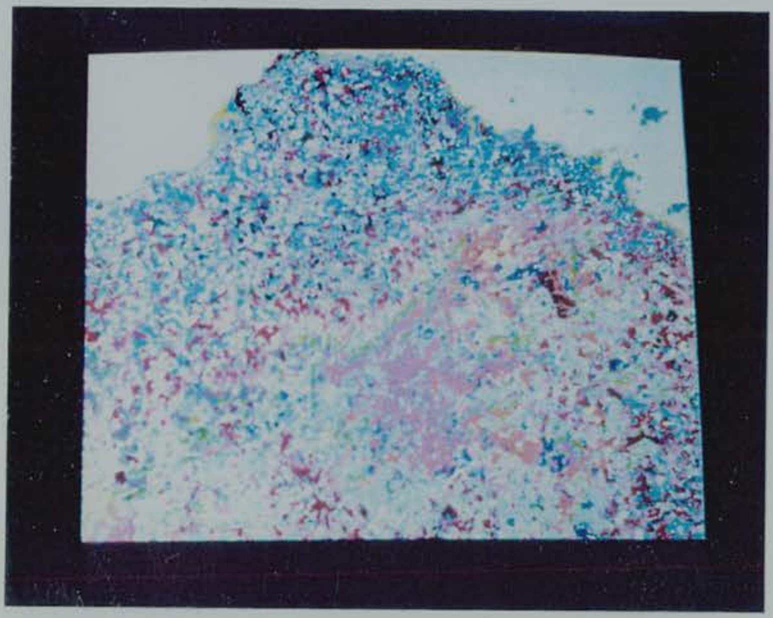


Plate (b). Classification of the TM image with twenty-eight spectral classes.

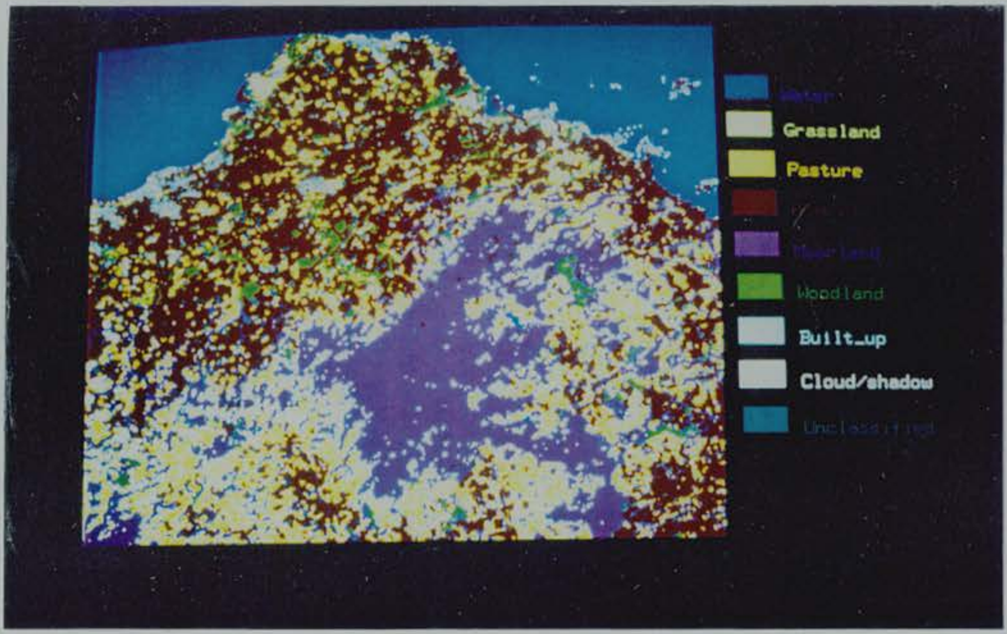


Plate (c). TM image classification with nine recoded information (feature) classes.

APPENDIX 8

Example of Command Files in ARC/INFO GIS

RUNXU84

```
define 5,.in
define 10,castda:dafs.scot84data
define 11,xu84,,c
run expl31:agrlist.AGRLISTO11
data     1984scotland
parishes     242-273,350-373,564-568
datacell     40,46,47,48,14,17,20,22,23,145,50
```

PARCALCS

```
 2      INTEGER PAR,L
        REAL R(1), Q(12)
        K=0
10      READ(10,*,END=99)L,PAR,Q
        K=K+1
        PAR=PAR+64000
        IF(Q(11).LT.0.5)GOTO 11
        R(1)=Q(11)*100/Q(12)
        GO TO 12
11      R(1)=0
12      WRITE(11)PAR,R
        WRITE(6,100)PAR,R
        GO TO 10
100     FORMAT(1I10,1F10.5)
101     FORMAT(6X,'NUMBER OF RECORDS READ=',I3)
 99     CONTINUE
        WRITE(6,101)K
        STOP
        END
```

AFFOREST.COM (Map 5.3)

```
ARC41
ARC
ARCPLOT
DISP 1039
AFFOREST
PAGESIZE 10 6.5
LINECOLOR 7
BOX 0 0 10 6.5
MAPEX OVERLAY
MAPUNITS METERS
MAPSCALE 250000
MOVE 0.8 6.2
TEXTCOLOR 7
TEXTSIZE 0.17
TEXTFONT 9
TEXT 'Areas of Afforestation 1984-1986'
TEXTSIZE 0.13
MOVE 7.7 5.75
TEXT 'Scale 1:250000'
#MOVE 0.4 0.05
#TEXTSIZE 0.09
TEXTFONT 2
#TEXT 'Compiled by H. Xu using ARC/INFO from Landsat data'
MOVE 7.7 0.05
TEXT 'Total area: 28.26 sq km'
SHADESET LSAT.SHD
RESEL OVERLAY POLYS GRID-CODE = 6 AND MSCLAS NE 6
POLYGONSHADE OVERLAY 3
LINECOLOR 1
#LINESIZE 2
STATISTICS OVERLAY POLYS
   SUM AREA
   END
ARCS U11:[HXU.MOD101]PARCLNC
Q
```

DEFOREST.COM (Map 5.4)

```
ARC41
ARC
ARCPLOT
DISP 1039
DEFOREST
PAGESIZE 10 6.5
LINECOLOR 7
BOX 0 0 10 6.5
MAPEX OVERLAY
MAPUNITS METERS
MAPSCALE 250000
MOVE 0.8 6.2
TEXTCOLOR 7
TEXTSIZE 0.17
TEXTFONT 9
TEXT 'Areas of Deforestation 1984-1986'
TEXTSIZE 0.13
MOVE 7.7 5.75
TEXT 'Scale 1:250000'
#MOVE 0.4 0.05
TEXTSIZE 0.09
TEXTFONT 2
#TEXT 'Compiled by H. Xu using ARC/INFO from Landsat data'
MOVE 7.7 0.05
TEXT 'Total area: 22.28 sq km'
SHADESET LSAT.SHD
RESEL OVERLAY POLYS MSCLAS = 6 AND GRID-CODE NE 6
POLYGONSHADE OVERLAY 5
LINECOLOR 1
#LINESIZE 2
ARCS U11:[HXU.MOD101]PARCLNC
Q
```

MSPLOT.COM (Map 5.1)

```
ARC41
ARC
ARCPLOT
DISP 1039
MSCLAS
PAGESIZE 10 6.5
BOX 0 0 10 6.5
MAPEX RDMOMSS
MAPUNITS METERS
MAPSCALE 250000
MOVE 0.8 6.15
TEXTCOLOR 5
TEXTSIZE 0.18
TEXTFONT 9
TEXT 'INTEGRATED CLASSIFICATION OF THE MSS IMAGE 1984'
TEXTSIZE 0.13
MOVE 7.7 5.75
TEXT 'Scale 1:250000'
SHADESET LSAT.SHD
RESEL RDMOMSS POLYS GRID-CODE = 1
POLYGONSHADE RDMOMSS 4
CLEARSEL
RESEL RDMOMSS POLYS GRID-CODE = 2
POLYGONSHADE RDMOMSS 8
CLEARSEL
RESEL RDMOMSS POLYS GRID-CODE = 3
POLYGONSHADE RDMOMSS 6
CLEARSEL
RESEL RDMOMSS POLYS GRID-CODE = 4
POLYGONSHADE RDMOMSS 2
CLEARSEL
RESEL RDMOMSS POLYS GRID-CODE = 5
POLYGONSHADE RDMOMSS 1
CLEARSEL
RESEL RDMOMSS POLYS GRID-CODE = 6
POLYGONSHADE RDMOMSS 3
CLEARSEL
RESEL RDMOMSS POLYS GRID-CODE = 7
POLYGONSHADE RDMOMSS 5
CLEARSEL
MOVE 7.85 4.5
TEXTFONT 2
KEYBOX 0.35 0.28
TEXTSIZE 0.12
KEYSEP 0.1 0.2
KEYSHADE MSCLAS.LEG
MOVE 8.1 4.9
TEXTSIZE 0.15
TEXT 'LEGEND'
MOVE 0.4 0.05
TEXTSIZE 0.08
TEXT 'Compiled by H. Xu using ARC/INFO from Landsat MSS data'
q
```

TMPLOT.COM (Map 5.2)

```
ARC41
ARC
ARCPLOT
DISP 1039
TMCLAS
PAGESIZE 10 6.5
BOX 0 0 10 6.5
MAPEX RDMOTM
MAPUNITS METERS
MAPSCALE 250000
MOVE 0.8 6.15
TEXTCOLOR 5
TEXTSIZE 0.18
TEXTFONT 9
TEXT 'INTEGRATED CLASSIFICATION OF THE TM IMAGE 1986'
TEXTSIZE 0.13
MOVE 7.7 5.75
TEXT 'Scale 1:250000'
SHADESET LSAT.SHD
RESEL RDMOTM POLYS GRID-CODE = 1
POLYGONSHADE RDMOTM 4
CLEARSEL
RESEL RDMOTM POLYS GRID-CODE = 2
POLYGONSHADE RDMOTM 8
CLEARSEL
RESEL RDMOTM POLYS GRID-CODE = 3
POLYGONSHADE RDMOTM 6
CLEARSEL
RESEL RDMOTM POLYS GRID-CODE = 4
POLYGONSHADE RDMOTM 2
CLEARSEL
RESEL RDMOTM POLYS GRID-CODE = 5
POLYGONSHADE RDMOTM 1
CLEARSEL
RESEL RDMOTM POLYS GRID-CODE = 6
POLYGONSHADE RDMOTM 3
CLEARSEL
RESEL RDMOTM POLYS GRID-CODE = 7
POLYGONSHADE RDMOTM 5
CLEARSEL
MOVE 7.85 4.5
TEXTFONT 2
KEYBOX 0.35 0.28
TEXTSIZE 0.12
KEYSEP 0.1 0.2
KEYSHADE MSCLAS.LEG
MOVE 8.1 4.9
TEXTSIZE 0.15
TEXT 'LEGEND'
MOVE 0.4 0.05
TEXTSIZE 0.08
TEXT 'Compiled by H. Xu using ARC/INFO from Landsat TM data'
q
```

CHANGE.COM (Map 5.5)

```
ARC41
ARC
ARCPLOT
DISP 1039
CHANGE
PAGESIZE 10.2 6.5
TEXTCOLOR 7
LINECOLOR 7
BOX 0 0 10.05 6.5
MAPEX OVERLAY
MAPUNITS METERS
MAPSCALE 250000
MOVE 0.8 6.2
TEXTSIZE 0.17
TEXTFONT 9
TEXT 'Changes in Woodland Areas 1984-1986'
TEXTSIZE 0.13
MOVE 7.7 5.75
TEXT 'Scale 1:250000'
ARCS U11:[HXU.MOD101]PARCLNC
SHADESET LSAT.SHD
RESEL OVERLAY POLYS MSCLAS = 6 AND GRID-CODE = 2
POLYGONSHADE OVERLAY 8
CLEARSEL
RESEL OVERLAY POLYS MSCLAS = 6 AND GRID-CODE = 3
POLYGONSHADE OVERLAY 6
CLEARSEL
RESEL OVERLAY POLYS MSCLAS = 6 AND GRID-CODE = 4
POLYGONSHADE OVERLAY 2
CLEARSEL
RESEL OVERLAY POLYS MSCLAS = 6 AND GRID-CODE = 5
POLYGONSHADE OVERLAY 1
CLEARSEL
RESEL OVERLAY POLYS MSCLAS = 6 AND GRID-CODE = 7
POLYGONSHADE OVERLAY 5
CLEARSEL
RESEL OVERLAY POLYS MSCLAS = 2 AND GRID-CODE = 6
POLYGONSHADE OVERLAY 3
CLEARSEL
RESEL OVERLAY POLYS MSCLAS = 3 AND GRID-CODE = 6
POLYGONSHADE OVERLAY 4
CLEARSEL
MOVE 7.9 4.5
TEXTFONT 2
KEYBOX 0.35 0.28
TEXTSIZE 0.09
KEYSEP 0.1 0.2
KEYSHADE CHANGE.LEG
MOVE 8.15 4.9
TEXTSIZE 0.15
TEXT 'LEGEND'
Q
AHPLOT CHANGE
```

ARCEDIT.COM

```
ARC41
ARC
ARCEDIT
DISP 4111
CREATECOV PARANNO PARCLNC
BACKCOV PARCLNC 2
BACKENV ARCS
DRAWENV ANNO
EDITF ANNO
DRAW
ANNOSIZE 600
ANNOTYPE LINE
ADD
...
SEL
DELETE
ADD
SAVE
Q
```

<u>PARANNO.COM (Figure 3.2)</u>

```
ARC41
ARC
ARCPLOT
DISP 1039
PARANNO
MAPEX PARCLNC
MAPUNITS METERS
MAPSCALE 350000
LINECOLOR 1
ARCS PARCLNC
LINE COLOR 7
TEXTCOLOR 7
ANNOTEXT PARANNO
PAGESIZE 10 6.8
BOX 0 0 10 6.8
MOVE 7 6
TEXTSIZE 0.19
TEXTFONT 9
TEXT 'The Study Area'
MOVE 7.7 5.5
TEXTSIZE 0.13
TEXT 'Scale 1:350000'
MOVE 0.4 0.05
TEXTFONT 2
TEXTSIZE 0.08
TEXT 'Compiled by H. Xu using ARC/INFO from Ordnance Survey maps'
Q
```

UNION.COM

```
$set def geomax$dub2:[gemsdata.hxu.mod101]
$arc
union rdmomss rdmotm overlay
q
```

```
BUILD PARCLNB LINE

ADDITEM PARCLNB.AAT PARCLNB.AAT VALUE 3 3 I

ARC:INFO
        >ARC
        >SELECT PARCLNB.AAT
        >CALCULATE VALUE = 250
        >Q STOP

ARC:CREATE PARCLNC PARCLNB
        INFO
        >SEL PARCLNC.TIC
        UPDATE XTIC =
            YTIC =
        ...
        >Q STOP

ARC: TRANSFORM PARCLNB PARCLNC

ARC: LINEGRID PARCLNC PARISH.SVF VALUE
        GRIDTYPE 1
        ORIGIN BL COORD
        CELL SIZE 50,50
        GRID SIZE R x C (ROW AND COLUMN)
        BACKGROUND 0
$RUN GEOVX$DUA1:[BOSS.JATYTAPE]SVFTOIMG
        INPUT FILE:   .SVF
        OUTPUT FILE: GEOVAX$DUB2:[GEMSDATA.HXU]FILENAME
```

INNEROVER.PLT (Map 5.7)

```
ARC50
ARC
DISP 1039
MAPEX INNEROVER
MAPUNITS METERS
MAPSCALE 150000
PAGESIZE 10 6.5
MAPLIMITS 1 0.5 10 6.5
ARCS INNER
BOX 0 0 9.2 6.3
SHADESET LSAT.SHD
RESEL INNEROVER POLYS GRID-CODE = 6 AND MSCLAS NE 6
POLYGONSHADE INNEROVER 3
STATISTICS INNEROVER POLYS
  SUM AREA
  END
CLEARSEL
RESEL INNEROVER POLYS MSCLAS = 6 AND GRID-CODE NE 6
POLYGONSHADE INNEROVER 2
STATISTICS INNEROVER POLYS
  SUM AREA
  END
MOVE 0.5 5.7
TEXTSIZE 0.16
TEXTFONT 9
TEXT 'Afforestation and Deforestation 1984-86 at Innerwick'
move 6.8 5.1
textsize 0.15
textfont 2
text 'Scale 1:150000'
move 6 4.2
text 'LEGEND'
move 5.9 3.8
textsize 0.12
keybox 0.35 0.28
keysep 0.1 0.2
keyshade test.leg
move 0.5 0.1
textsize 0.1
text 'Completed by H. Xu using ARC/INFO GIS'
box 5.9 2.5 6.25 2.78
box 5.9 1.9 6.25 2.18
move 6.4 2.64
text 'river'
move 6.4 2
text 'parish boundary'
linercolor 4 (blue)
arcs u11:[hxu.mod101]river
q
```

APPENDIX 9

List of Acronyms

ATM	Airborne Thematic Mapper
AVHRR	Advanced Very High Resolution Radiometer
CAP	Common Agricultural Policy
CCS	Countryside Commission for Scotland
CLDS	Canada Land Data System
DAFS	Department of Agriculture and Fisheries for Scotland
DoE	Department of the Environment
DTM	Digital Terrain Model(s)
EEC	European Economic Community
ERS-1	European Remote Sensing Satellite-1
ESA	European Space Agency
GCP	Ground Control Point
GIRAS	Geographic Information Retrieval and Analysis System
GIS	Geographical Information System
IFOV	Instantaneous Field Of View
ITE	Institute of Terrestrial Ecology
LACIE	Large Area Crop Inventory Experiment
LUNR	Land Use and Natural Resource
MLURI	Macaulay Land Use Research Institute
MSS	Multi-Spectral Scanner
NCC	Nature Conservancy Council
NCMS	National Countryside Monitoring Scheme
NERC	Natural Environmental Research Council
NPRA	National Petroleum Reserve in Alaska
NRSC	National Remote Sensing Centre
OS	Ordnance Survey
RBV	Return Beam Vidcon
RLUIS	Rural Land Use Information System
SDD	Scottish Development Department
TM	Thematic Mapper
USGS	United States Geological Survey

APPENDIX 10

Published Papers

Published in Proceedings of IGARSS'89, Vancouver, July. 1989

SYNERGISM OF REMOTELY SENSED AND CONTEXTUAL DATA TO MONITOR CHANGES IN LAND USE

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ABSTRACT

This paper examines the feasibility of LANDSAT image data in land use studies for a test location in South-East Scotland. Integration of remotely sensed data and contextual data is achieved by using an interface between GEMSTONE-35 image processing system and ARC/INFO Geographic Information System (GIS). Included are: classification of land use/land cover, accuracy assessment, transformation of classified image to GIS and comparison of results for different dates. Analysis on the TM image of September 14, 1986 has been completed. The overall accuracy of the image classification was assessed as 88%. Along with a discussion on the research results and difficulties in image analyses, preliminary conclusions are drawn that the synergism of remotely sensed and contextual data is of substantial significance in land use studies.

KEY WORDS: Remote Sensing, GIS, Interface, Overlay, Classification, Land Use.

1. INTRODUCTION

Major changes in land use will take place in Europe in the immediate years ahead as the effects of how policies change on agricultural support become felt. Satellite imagery affords a means of monitoring changes in land use and updating information on the distribution and dynamics of land use. Using satellite imagery successfully as a regular input for land use monitoring in Scotland requires a measure of luck in being able to obtain usable imagery on a routine basis and substantial contextual knowledge of the ground situation to counter this and the subtlety of the changes in land cover. One of the characteristics of land use in Scotland is the complexity within a short distance. This leads to difficulties in analysing satellite images. Therefore incorporation of ancillary data and a prior knowledge are of special value.

This paper examines the application and the feasibility of LANDSAT image data in land use studies for a test location in South-East Scotland and seeks to establish a feasible approach to monitoring recent changes in land use. Integration of the data is achieved by using an interface, which has been developed in the Department of Geography, University of Edinburgh, between the GEMSTONE-35 image processing system and ARC/INFO-ORACLE. Image analysis is the principal thrust of the study and the major procedure includes: definition of a classification system, classification of land use/land cover, post-classification filtering, accuracy assessment, transformation of classification results to GIS and comparison of results for different dates. Finally it is followed by a critical discussion based on the research results, concerning the classification accuracy and the usefulness of the LANDSAT imagery and its potential synergism with contextual data.

2. METHODOLOGY

The adopted methodology involves several steps. First is the selection of the study area. The Lammermuir Hills area in South-East Scotland covers different land use zones from lowland to upland and has experienced such changes as afforestation of former moorland, conversion of rough pasture to improved grassland and expansion of arable land towards the upland over the past four decades (Eadie, 1984). Availability of a range of data and easy access to the area for ground truth work also influenced this choice of a study area.

The datasets for the study included: the yearly Farm Cropping Programme by the Edinburgh Centre of Rural Economy which provides valuable reference information on ground truth data; images for two dates with one being MSS data for April 24, 1984 and the other TM data for September 14, 1986; and additional cartographic data from topographic maps, maps of land capability for agriculture, and soil maps, which provide a basis for improving classification of the LANDSAT imagery.

GEMSTONE-35 is a 1024 x 1024 workstation with its own integral 68020-based processor and is linked to a MICROVAX computer for access to the satellite data and file management. With up to 27 image stores, the GEMSTONE system can perform a wide variety of processing operations. ARC/INFO-ORACLE was developed in the Department of Geography, University of Edinburgh and is interfaced with the GEMSTONE-35 system via a series of programs. Classified raster image files can be transformed into ARC/INFO vector format and recoded into new class groupings whilst ARC/INFO polygon and arc coverages can be converted into GEMSTONE image format for manipulation in the image processing environment.

Prior to the image classification, geometric correction of LANDSAT imagery helps to eliminate spatial distortions of the image, stemming from many factors which affect the collection of remotely sensed data. Mergence with other datasets and transference between vector and raster data also require that both image and the digital cartographic data layers are geometrically corrected to the same coordinate system. In this study, one TM image and one MSS image have been corrected for the study area. The output images have been registered to the British National Grid coordinate system. The pixel sizes have been resampled to 50m x 50m in order to overcome problems resulting from the different spatial resolutions of the two images.

A second step prior to classification was to gather ground truth data for training the classifier and generating the statistics. The yearly Farm Cropping Programme by the Edinburgh Centre of Rural Economy provided a means to assist discrimination between fields with different crops. The aspatial data of agricultural statistics were mapped into spatial form. The resultant map was used as ground truth data for defining training areas. In addition, aerial photographs and Ordnance Survey maps were also used to assist in defining areas. The statistics generated from the training areas were then saved and used for the image classification. The integrated land cover classification was carried out on a pixel by pixel basis using a Maximum Likelihood Classifier.

LANDSAT image classification has enabled rapid generation of land cover maps. But user acceptance has lagged behind due to the difficulties in the specification and statistical testing of accuracy. In this study, a post-classification median filter was applied to remove isolated pixels. The proportion of mixed pixels remaining unclassified was also reduced to a large extent after the filtering. Accuracy assessment of the classification performance was then made by random sampling of individual areas for each class to examine inclusive and exclusive classification errors. Finally, satisfactory classification results for different dates can be compared to show changes in land use. This can be achieved by transferring the digital classification results to ARC/INFO-ORACLE after recoding each class to a new group.

3. CURRENT RESEARCH STATUS

Imagery analysis on the TM data of September 14, 1986 has been completed.

After contrast stretching the image bands 3,4 and 5, ground control points were chosen by identifying recognisable points from both the image and the Ordnance Survey 1:50000 map sheets. Then using GEMSTONE modules, the image was geometrically corrected and the pixel size was resampled from its original 30m x 30m to 50m x 50m. The cubic convolution method was chosen for the interpolation of the output pixel intensity. The relationship between image coordinates and ground coordinates was also established for the area delimited by British National Grid Coordinates.

Then twenty-eight areas were defined with the help of the aforementioned Farm Cropping Programme, aerial photographs and other ancillary data incorporated through ARC/INFO. A prior knowledge of the ground situation and visual interpretation of the image also played a part in defining the training areas.

The statistics generated from those twenty-eight areas were saved and used to classify subscenes of the image. The segmentation of the image to subscenes for classification helped to reduce certain obvious errors. For example, pixels classified as built-up areas on the moors and built-up areas classified as moors can be readily excluded. Classification results on subscenes were then copied into one image with the same pixel size and location as prior to the classification. This combined image shows the image classification results for the whole study area.

The image containing classification results was enhanced by applying a median filter to exclude isolated pixels. The image file was further recoded into new groupings for rapid combination of classes prior to transference to ARC/INFO or for redisplay on the GEMSTONE workstation. The number of class after the recoding was reduced from 28 to 9, namely, water surface, grassland, pasture, arable land, moorland, forest land, built-up area, cloud/shadow and unclassified area.

An accuracy assessment was then carried out on seven of those nine classes. Cloud/shadow and the unclassified areas were ignored. The random sampling of the individual pixels was applied to each class with a sample size determined by its weight in the whole image and the assumed prior accuracy (Hay, 1979; Rosenfield, 1982). Each sample point was then checked with updated Ordnance Survey 1:25000 map sheets and supplemented by field checking. A prior knowledge also permits a decision to accept or reject the classification of certain pixels. A contingency table was thus presented (Table.1). As van Genderen (1977) demonstrated, this table shows the following aspects:

** The frequency that any one land use type (on the ground) is erroneously attributed to another class, as those values in Row F1 of Table.1.

** The frequency that the wrong land use (as observed on the ground) is erroneously included in any one class, e.g., those in column F2 of table.1.

** The proportion of all sampled pixels which are misclassified. In this case, 42/363 of all attributions are incorrect.

** The determination of whether the errors are random or subject to a persistent bias.

Thus the overall accuracy was assessed as 88 per cent with an accuracy for each class better than 77 per cent. In general, the classification performance was satisfactory, although certain classes such as grassland could not satisfy the general criteria proposed by Loelkes et al (1983), where the minimum level of interpretation accuracy in identifying land use/land cover categories from remote sensing data should be at least 85 per cent.

Using the integration between GEMSTONE image processing system and ARC/INFO GIS, the results of classification were transferred to ARC/INFO as a new thematic overlay for further use.

A number of important points about using remote sensing image and the classification performance need to be made as follows.

First of all, the effect of clouds and shadows seemed a problem which precluded a complete study of the image. In the TM image, the classified clouds and shadows took 1.24 per cent of the pixels in the whole scene within the study area. Apart from the fact that areas under clouds or shadows will not give any information on land use, the existence of clouds and shadows may affect the classification performance. For instance, some of the dark shadow areas had very low spectral reflectance values and therefore were

		LAND USE (on the ground)								
		water	grass	pasture	arable	moorland	forest	built-up	total	F2
LAND USE (image classification)	water	26							26	0
	grass		37	2	8		1		48	11/48
	pasture		4	45		1	2		52	7/52
	arable		5		108			6		11/119
	moorland			3		29	4		36	7/36
	forest						51		51	0
	built-up				5	1		25	31	6/31
	total	26	46	50	121	31	58	31	363	
	F1	0	9/46	5/50	13/121	2/31	7/58	6/31		42/363

Table 1. Numbers of Sampled Pixels in Actual and Classified Land-use Categories

misclassified as water whereas they were actually crop lands. As aforementioned, it is quite difficult to get cloud free images in Scotland. Thus the incorporation of ancillary data such as land use survey from other sources is crucial. Work by Gurney (1983) has shown that contextual methods can be used in separation of cloud and cloud shadow from the remainder of a satellite scene. To achieve this, the synergism of remote sensing and contextual data is of particular value and significance.

Another problem arose from the definition of a category of land use. One example can be the definitions of grassland, pastures and arable land. By broad definition, grasslands include heath, bracken and other rough grassland and pastures are mainly the improved grassland while arable lands comprise crop land and fallows. On the image, these three land uses may have a very similar spectral reflectance at the time when the image was taken. Therefore classification errors may occur easily. This would affect the overall classification performance. From Table 1, it can be seen that 8 out of 11 pixels which were misclassified as grasslands were attributed to arable lands and 4 out of 7 errors for pastures were attributed to grasslands. To overcome those difficulties, more detailed ground truth data and certain image enhancements prior to the classification may be helpful.

Finally, whilst post-classification filtering helped to remove isolated pixels and reduce the proportion of the unclassified pixels, it affected the classification to some extent. Small areas may be merged into their neighbouring land uses, e.g., a farm house or a road next to croplands may be represented as arable land on the classified image after the filtering. Considering the characteristics of land use in Scotland, where subtle variations occur within a short distance, the effect of merging should not be ignored completely.

4. PRELIMINARY CONCLUSIONS

Results so far have shown the great potential of LANDSAT imagery in area measurement and mapping spatial distribution of land cover types. The integration of remote sensing and GIS techniques is of substantial significance in land use studies. Remote sensing generates a wide variety of data as an input to update GIS data planes while GIS provides an efficient use of the ancillary data required by remote sensing analysis and enables relationships between datasets to be explored and tested.

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Published in Proceedings of GIS/LIS Vol. 1. pp95

MONITORING CHANGES IN LAND USE THROUGH INTEGRATION OF REMOTE SENSING AND GIS

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Abstract--*This paper evaluates the results of attempting to monitor changes in land use through integration of remote sensing and GIS for a test location of diverse land cover types in South-East Scotland. Based upon the analysis of images for two dates, the major approach includes: classification of land use/land cover on image segmentations, accuracy assessment, transference of classified images to ARC/INFO GIS, and comparison of results for different dates. The emphasis is placed on examplifying the presentation and comparison of classification results. Whilst it is felt insufficient to carry out an integrated classification on the basis of single date image analysis, the research results have demonstrated the potential and advantages of the integration of remote sensing and GIS and present a way forward for land use study.*

Key word: Remote sensing, GIS, interface, classification, land use.

INTRODUCTION

Detection of changes in land use and updating information on the distribution and dynamics of land use have long term significance in policy making and scientific research. The outcome of integrating information extracted from remotely sensed data with other data types by using GIS methods enhances greatly the information content of the remotely sensed data and provides a highly flexible, efficient means of establishing a datum for subsequent monitoring of land use.

Aiming at establishing a feasible approach to monitoring changes in land use, this paper presents such an example for a test location in South-East Scotland with the integration of remote sensing and GIS, using an interface, which has been developed in the Department of Geography, University of Edinburgh, between the GEMSTONE-35 image processing system and the ARC/INFO GIS. Images for two dates were used in the research, with one being MSS data for April 24, 1984 and the other TM data for September 14, 1986. The yearly Farm Cropping Programme of the Edinburgh Centre of Rural Economy provided valuable ground truth data for classification of the imagery. Additional cartographic data from topographic maps and maps of land capability for agriculture were incorporated into the GEMSTONE-35 environment through digitising this information in GIS to improve classification of the Landsat imagery.

As described by Xu and Young in 1989 [8], the major procedure for the image analysis includes: definition of a classification system, classification of land use/land cover, post-classification filtering, accuracy assessments, transference of image classification results to the ARC/INFO GIS, and comparison of results for different dates. The benefits and further problems requiring solution were also examined in that paper, based upon the completion of the TM image analysis. These included to exemplify the improvement in classification by reducing the number of unclassified or improperly classified pixels, and problems remained in the application of remote sensing image and the classification performance.

The present paper provides a full report of the imagery analysis based on the completion of images for two dates. Whilst the major approach and outcome of the imagery analysis are briefly explained, the emphasis is placed on the presentation and comparison of classification results. Finally, conclusions are drawn upon the advantages and difficulties of the integration of remote sensing and GIS in land use study in an area of diverse land cover types.

METHODOLOGY AND RESULTS

Imagery analysis is the principal thrust of the research. Prior to the classifications, both images were geometrically corrected. The pixel size was resampled to 50 m x 50 m and all pixels for the defined image area were registered to British National Grid co-ordinates on completion of the geometric correction, to within a two pixel accuracy.

ALL MATERIAL IN THIS SP

Then training areas and statistics were mainly extracted with the help of the Farm Cropping Plan record data and other ancillary topographic data. Visual interpolation by the analyst was also found useful in selecting the training areas. More than one spectral class was defined in order to adequately train on certain feature. For instance, the information class of water surface in the final classification output was represented by spectral classes which separated deep clear water such as reservoirs from shallow water such as beach or river-side water. Progressive refinement of training data formed another important and time-consuming part in obtaining good statistics for image classification.

Segmentation of images was applied manually according to the ground features and the characteristics of the image scene. Then, integrated classification of land use/land cover for each image was carried out on each segmentation using a Maximum Likelihood classifier with different sets of statistics. This classification of different segments helped to avoid some obvious errors in classification, *e.g.*, pixels classified as built-up areas on areas known to be moorland and built-up areas misclassified as moors can be readily excluded. A 7 x 7 post classification majority mode filter was used for each classified image to remove isolated pixels in a uniformed field and to reduce the number of unclassified pixels. Then the classified image files were further recoded into new groups representing feature classes for rapid combination of classes prior to transference to ARC/INFO or for redisplay on the GEMSTONE workstation. The reduced number of classes can substantially reduce the number of polygons in the resultant coverage after the vectorising process because for each region of similarly classified pixels in an image, vectorisation is performed by tracing the boundary pixels between classes.

Accuracy assessment of the classification performance was made by a random sampling of individual areas of known cover types to examine the inclusive and exclusive classification errors for each feature class. The overall accuracy for the TM image classification was assessd as 88% and 82% for the MSS image. Details on the method and presentation of results are discussed in Xu and Young (1989) [8].

Finally, the classification results for different dates with adequate accuracies were compared to show changes in land use. This was achieved either by working on the GEMSTONE image processing system or by transferring the digital classification results to ARC/INFO. Information on both the spatial distribution and the quantitative statistics concerning the changes were shown subsequently (Map 1).

PRESENTATION AND COMPARISON OF RESULTS

The presentation and comparison of the classification results can be achieved by using either the GEMSTONE image processing system or the ARC/INFO GIS.

Detection of changes using image processing system--Once the image classification and recoding were completed, it is relatively easy to compare the results to detect changes in one type of land use for a defined area. The ground area for each category was also estimated. The following example shows the procedures for this using GEMSTONE Modules.

Example 1: Detection of changes in forestry

<u>Making masks from images</u>

A mask is a special kind of image whose pixels only have values of 0 or 255. It is used to show those parts of a region conforming to a particular type, such as forestry. A pixel value of 255 in the mask indicates an occurrence of the given type in the corresponding cell while a value of 0 indicates its absence. A mask can be created by applying a density slice to the recoded image of classification so that the areas of the specified type (*e.g.* forestry in this case) are displayed in white and all other areas in black. The GEMSTONE Copy module was then used to store the displayed image such that white pixels were copied with the value 255 and black pixels with the value 0. For example, two masks were created to show the forestry distribution in both images: Mask 1 describes areas of forestry in 1984 and Mask 2 describes those that were under forest in 1986.

<u>Define programs in Arithmetic menu</u>

The symmetrical difference of the two masks, which shows those areas on either mask that are not on the other, can be found by using the **XOR** (exclusive-or) logical operation available in the GEMSTONE Arithmetic module. For instance:

store 1: - [mask1] XOR [mask2]

Thus store 1 shows the areas of change in forestry between 1984 and 1986. Then the areas deforested since 1984 are given by

[mask1] AND store 1

and the areas afforested since 1984 by

[mask2] AND store 1.

The **AND** function produces the intersection of the two masks, *i.e.*, the pixels which have values of 255 in both.

Distribution and statistics

Apart from showing the spatial distribution of changes in forestry, quantitative statistics can be derived. The pixel numbers within each mask were counted using the density-slice module, taking all the pixels with a value of 255 as belonging to one density slice. Then the corresponding ground area was estimated by multiplying the number of pixels in the slice by the area of a single cell which was 50 x 50 square metres. Strictly, this method should only be used to estimate areas where terrain is flat. The woodland areas in 1984 and 1986, and the afforestation and deforestation which took place during the period can be worked out, as shown in Table 1.

Table 1 shows the total number of pixels in the image, with the number of pixels included in each slice and the percentage of the total that this represents.

	Pixel Number	Per cent	Area (km^2)
Forestry-84	20891	3.31	52.23
Forestry-86	23286	3.69	58.22
Deforestation	8910	1.41	22.28
Afforestation	11305	1.79	28.26
Total pixels= 631601			

Table 1 Changes in forestry 1984-1986

Presentation and comparison of results in ARC/INFO GIS--After evaluating their accuracy, the results of the classification were transferred to ARC/INFO using the GEMSVF and GRIDPOLY modules of the GEMSTONE-35 to ARC/INFO interface. The classification results were presented using a high quality plotter. Some functions of ARC/INFO GIS on coverage manipulations also helped answer questions automatically concerning where the change was, what the change was, *i.e.*, from which to which, how the land use has changed, and to what extent the change has occurred, etc.

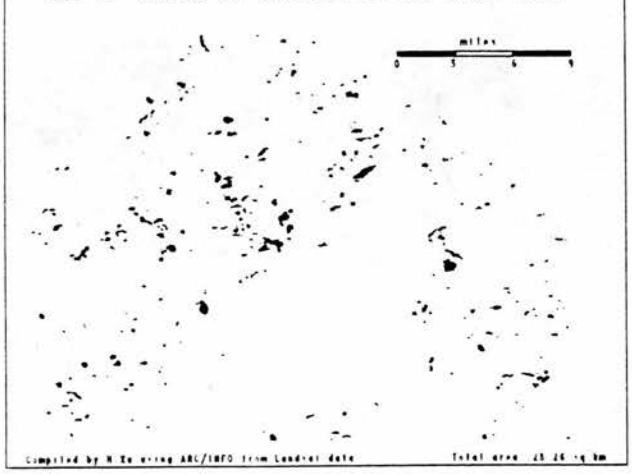
The classification results were presented on ARC/INFO using a high quality plotter. Maps showing the classification results for the MSS image and the TM image offer several advantages over the hard copy of the imagery data. They are registered to the selected ground coordinate system (British National Grid) so that they can be manipulated as new thematic overlays in the GIS. Thereafter, the maps can be scaled and designed in a flexible way without the requirements for photogrammetric skills or expensive printing. Examples of those maps are not presented in this paper due to space limitation. However, some of the advantageous characteristics can be demonstrated in Map 1 as follows.

Apart from an automated high quality plotting, ARC/INFO inter-relates the attribute and locational components. The **UNION** function creates new polygons by overlaying polygons from two coverages and associating their attributes with each new polygon. It combines two polygon coverages while keeping all features from both coverages. Items from the input and union coverages are merged in the output coverage. Therefore, again taking woodland for example, information on afforestation or deforestation, or the areas of afforestation which took place on arable land or rough grazing etc can be easily obtained by selecting certain features in the new overlay coverage. Both the spatial distribution and the attribute data can be shown subsequently (see Map 1 as an example). Map 1 shows the areas of afforestation for the test location from 1984 to 1986. The total area of afforestation is 28.26 square kilometres. The map can be shown in a selected scale once it is stored in ARC/INFO GIS.

DISCUSSION

Results with adequate accuracy of integrated classification for both images have been achieved using the statistics generated from progressive refinement of training data and were enhanced by applying a post-classification majority-mode filter. The improved analysis shows the benefits of integrating data from GEMSTONE image processing system and ARC/INFO GIS. GIS can provide ancillary data required for the imagery analysis. It also helps the analyst to acquire additional knowledge in defining training areas and in image segmentation where it is necessary. On the other hand, imagery classification offers new thematic overlays in a regional GIS, which is often needed for the purpose of monitoring changes over time in land use. An automated high quality plotting of the classification results forms another advantage of the integration of the two techniques.

Previous studies have demonstrated the potential of image classification and GIS for single resource analysis [*e.g.* 2 and 6]. This study is different from the others in that an integrated classification of land use/land cover was carried out for each image. The integrated results should not be taken as simply the sum of single classes. The decision-making comes from a combined situation and therefore is expected to be more realistic. Also, this study provides an example of the realisation of the integration between remote sensing and GIS. It enables the interpreter to go beyond that of abstract ideals,



MAP 1 AREAS OF AFFORESTATION 1984-1986

assumptions or predictions. Therefore the advantages and problems of image classifications and comparison of results to see changes in land use can be demonstrated and justified in a practical way.

Whilst integrated classification offers advantages over single resource identification, difficulties were encountered for delineating certain feature classes with the single date image. It is felt insufficient to carry out an integrated classification on the basis of one image analysis. Multi-temporal analysis is essential. More images at higher cost in a realistic time need to be analysed in order to monitor routinely changes in land use. Using the present approach, integration of the remote sensing data into a GIS is time consuming and demanding of intensive CPU time. Further improvements are needed to develop more efficient means of achieving results of the same order as these described in this paper.

CONCLUSIONS

In conclusion, the research results have demonstrated the potential and advantages of the integration of remote sensing and GIS in land use study. More importantly, it has put the integration of two technologies into realisation instead of them remaining abstract ideals. Hopefully, the research presents a way forward for land use study, with rapid developments and wider applications of remote sensing and GIS.

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